CHAPTER 11
AIRCRAFT ELECTRICAL SYSTEMS

GENERAL

The satisfactory performance of any modern aircraft depends to a very great degree on the continuing reliability of electrical systems and subsystems. Improperly or carelessly installed wiring or improperly or carelessly maintained wiring can be a source of both immediate and potential danger. The continued proper performance of electrical systems depends on the knowledge and techniques of the mechanic who installs, inspects, and maintains the electrical system wires and cables.

Procedures and practices outlined in this section are general recommendations and are not intended to replace the manufacturer's instructions and approved practices.

For the purpose of this discussion, a wire is described as a single, solid conductor, or as a stranded conductor covered with an insulating material. Figure 11–1 illustrates these two definitions of a wire.

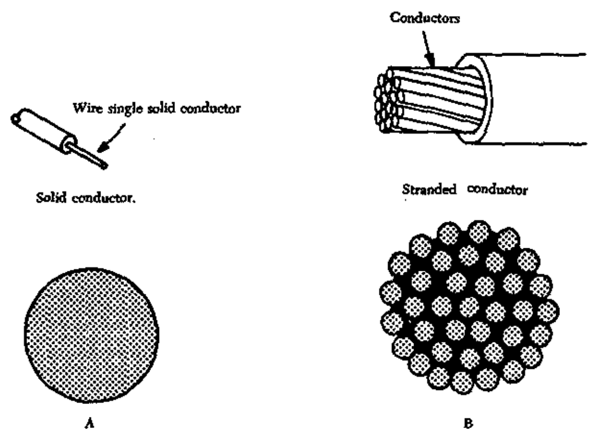


FIGURE 11–1. Two types of aircraft wire.

The term cable, as used in aircraft electrical installations, includes:

(1) Two or more separately insulated conductors in the same jacket (multi-conductor cable).

(2) Two or more separately insulated conductors twisted together (twisted pair).

(3) One or more insulated conductors, covered with a metallic braided shield (shielded cable).

(4) A single insulated center conductor with a metallic braided outer conductor (radio frequency cable). The concentricity of the center conductor and the outer conductor is carefully controlled during manufacture to ensure that they are coaxial.

Wire Size

Wire is manufactured in sizes according to a standard known as the AWG (American wire gage). As shown in figure 11–2, the wire diameters become smaller as the gage numbers become larger. The largest wire size shown in figure 11–2 is number 0000, and the smallest is number 40. Larger and smaller sizes are manufactured but are not commonly used.

A wire gage is shown in figure 11–3. This type of gage will measure wires ranging in size from number zero to number 36. The wire to be measured is inserted in the smallest slot that will just accommodate the bare wire. The gage number corresponding to that slot indicates the wire size. The slot has parallel sides and should not be confused with the semicircular opening at the end of the slot. The opening simply permits the free movement of the wire all the way through the slot.

Gage numbers are useful in comparing the diameter of wires, but not all types of wire or cable can be accurately measured with a gage. Large wires are usually stranded to increase their flexibility. In such cases, the total area can be determined by multiplying the area of one strand (usually computed in circular mils when diameter or gage number is known) by the number of strands in the wire or cable.

Factors Affecting the Selection of Wire Size

Several factors must be considered in selecting the size of wire for transmitting and distributing electric power.

Gage number	Diameter (mils)	Cross section: Circular mils	Cross section: Square inches	Ohms per 1,000 ft.: 25°C. (=77°F.)	Ohms per 1,000 ft.: 65°C. (=149°F.)
0000	460.0	212,000.0	0.166	0.0500	0.0577
000	410.0	168,000.0	.132	.0630	.0727
00	365.0	133,000.0	.105	.0795	.0917
0	325.0	106,000.0	.0829	.100	.116
1	289.0	83,700.0	.0657	.126	.146
2	258.0	66,400.0	.0521	.159	.184
3	229.0	52,600.0	.0413	.201	.232
4	204.0	41,700.0	.0328	.253	.292
5	182.0	33,100.0	.0260	.319	.369
6	162.0	26,300.0	.0206	.403	.465
7	144.0	20,800.0	.0164	.508	.586
8	128.0	16,500.0	.0130	.641	.739
9	114.0	13,100.0	.0103	.808	.932
10	102.0	10,400.0	.00815	1.02	1.18
11	91.0	8,230.0	.00647	1.28	1.48
12	81.0	6,530.0	.00513	1.62	1.87
13	72.0	5,180.0	.00407	2.04	2.36
14	64.0	4,110.0	.00323	2.58	2.97
15	57.0	3,260.0	.00256	3.25	3.75
16	51.0	2,580.0	.00203	4.09	4.73
17	45.0	2,050.0	.00161	5.16	5.96
18	40.0	1,620.0	.00128	6.51	7.51
19	36.0	1,290.0	.00101	8.21	9.48
20	32.0	1,020.0	.000802	10.4	11.9
21	28.5	810.0	.000636	13.1	15.1
22	25.3	642.0	.000505	16.5	19.0
23	22.6	509.0	.000400	20.8	24.0
24	20.1	404.0	.000317	26.2	30.2
25	17.9	320.0	.000252	33.0	38.1
26	15.9	254.0	.000200	41.6	48.0
27	14.2	202.0	.000158	52.5	60.6
28	12.6	160.0	.000126	66.2	76.4
29	11.3	127.0	.0000995	83.4	96.3
30	10.0	101.0	.0000789	105.0	121.0
31	8.9	79.7	.0000626	133.0	153.0
32	8.0	63.2	.0000496	167.0	193.0
33	7.1	50.1	.0000394	211.0	243.0
34	6.3	39.8	.0000312	266.0	307.0
35	5.6	31.5	.0000248	335.0	387.0
36	5.0	25.0	.0000196	423.0	488.0
37	4.5	19.8	.0000156	533.0	616.0
38	4.0	15.7	.0000123	673.0	776.0
39	3.5	12.5	.0000098	848.0	979.0
40	3.1	9.9	.0000078	1,070.0	1,230.0

FIGURE 11–2. American wire gage for standard annealed solid copper wire.

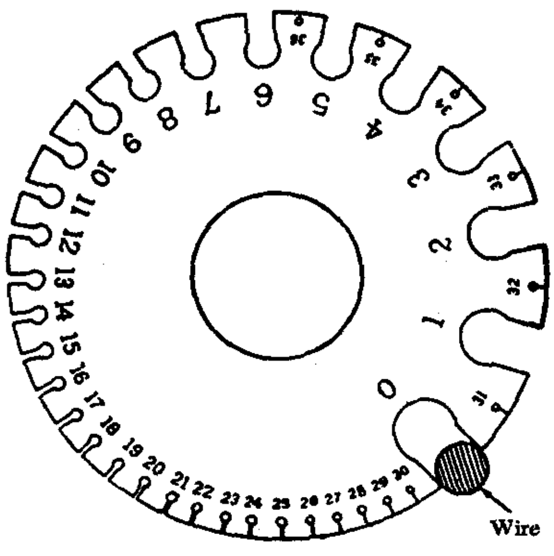


FIGURE 11–3. A wire gage.

One factor is the allowable power loss (I^2R loss) in the line. This loss represents electrical energy converted into heat. The use of large conductors will reduce the resistance and therefore the I^2R loss. However, large conductors are more expensive initially than small ones; they are heavier and require more substantial supports.

A second factor is the permissible voltage drop (IR drop) in the line. If the source maintains a constant voltage at the input to the lines, any variation in the load on the line will cause a variation in line current and a consequent variation in the IR drop in the line. A wide variation in the IR drop in the line causes poor voltage regulation at the load. The obvious remedy is to reduce either current or resistance. A reduction in load current lowers the amount off power being transmitted, whereas a reduction in line resistance increases the size and weight of conductors required. A compromise is generally reached whereby the voltage variation at the load is within tolerable limits and the weight of line conductors is not excessive.

A third factor is the current-carrying ability of the conductor. When current is drawn through the conductor, heat is generated. The temperature of the wire will rise until the heat radiated, or otherwise dissipated, is equal to the heat generated by the passage of current through the line. If the conductor is insulated, the heat generated in the conductor is not so readily removed as it would be if the conductor were not insulated. Thus, to protect the insulation from too much heat, the current through the conductor must be maintained below a certain value.

When electrical conductors are installed in locations where the ambient temperature is relatively high, the heat generated by external sources constitutes an appreciable part of the total conductor heating. Allowance must be made for the influence of external heating on the allowable conductor current, and each case has its own specific limitations. The maximum allowable operating temperature of insulated conductors varies with the type of conductor insulation being used.

Tables are available that list the safe current ratings for various sizes and types of conductors covered with various types of insulation. Figure 11–5 shows the current-carrying capacity, in amperes, of single copper conductors at an ambient temperature of below 30°C. This example provides measurements for only a limited range of wire sizes.

Factors Affecting Selection of Conductor Material

Although silver is the best conductor, its cost limits its use to special circuits where a substance with high conductivity is needed.

The two most generally used conductors are copper and aluminum. Each has characteristics that make its use advantageous under certain circumstances. Also, each has certain disadvantages.

Copper has a higher conductivity; it is more ductile (can be drawn), has relatively high tensile strength, and can be easily soldered. It is more expensive and heavier than aluminum.

Although aluminum has only about 60% of the conductivity of copper, it is used extensively. Its lightness makes possible long spans, and its relatively large diameter for a given conductivity reduces corona (the discharge of electricity from the wire when it has a high potential). The discharge is greater when small diameter wire is used than when large diameter wire is used. Some bus bars are made of aluminum instead of copper where there is a greater radiating surface for the same conductance. The characteristics of copper and aluminum are compared in figure 11–4.

FIGURE 11–4. Characteristics of copper and aluminum.

Characteristic	*Copper*	*Aluminum*
Tensile strength (lb./in.^{2})	55,000	25,000
Tensile strength for same conductivity (lb.)	55,000	40,000
Weight for same conductivity (lb.)	100	48
Cross section for same conductivity (C. M.)	100	160
Specific resistance (Ω/mil ft.)	10.6	17

Size	Rubber or thermo-plastic	Thermoplastic asbestos, var-cam, or asbestos var-cam	Impregnated asbestos	Asbestos	Slow-burning or weather-proof
0000	300	385	475	510	370
000	260	330	410	430	320
00	225	285	355	370	275
0	195	245	305	325	235
1	165	210	265	280	205
2	140	180	225	240	175
3	120	155	195	210	150
4	105	135	170	180	130
6	80	100	125	135	100
8	55	70	90	100	70
10	40	55	70	75	55
12	25	40	50	55	40
14	20	30	40	45	30

FIGURE 11–5. Current-carrying capacity of wire.

Voltage Drop in Aircraft Wire and Cable

It is recommended that the voltage drop in the main power cables from the aircraft generation source or the battery to the bus should not exceed 2% of the regulated voltage when the generator is carrying rated current or the battery is being discharged at a 5-min. rate. The tabulation in figure 11–6 shows the recommended maximum voltage drop in the load circuits between the bus and the utilization equipment.

FIGURE 11–6. Recommended maximum voltage drop in load circuits.

Nominal system voltage	*Allowable voltage drop*	
	Continuous operation	*Intermittent operation*
14	0.5	1
28	1	2
115	4	8
200	7	14

The resistance of the current return path through the aircraft structure is always considered negligible. However, this is based on the assumption that adequate bonding of the structure or a special electric current return path has been provided and is capable of carrying the required electric current with a negligible voltage drop. A resistance measurement of 0.005 ohm from the ground point of the generator or battery to the ground terminal of any electrical device is considered satisfactory. Another satisfactory method of determining circuit resistance is to check the voltage drop across the circuit. If the voltage drop does not exceed the limit established by the aircraft or product manufacturer, the resistance value for the circuit is considered satisfactory. When using the voltage drop method of checking a circuit, the input voltage must be maintained at a constant value.

Instructions For Use of Electric Wire Chart

The charts in figures 11–7 and 11–8 apply to copper conductors carrying direct current. Curves 1, 2, and 3 are plotted to show the maximum ampere rating for the specified conductor under the specified conditions shown. To select the correct size of conductor, two major requirements must be met. First, the size must be sufficient to prevent an excessive voltage drop while carrying the required current over the required distance. Secondly, the size must be sufficient to prevent overheating of the cable while carrying the required current. The charts in figures 11–7 and 11–8 can simplify these determinations. To use these charts to select the proper size of conductor, the following must be known:

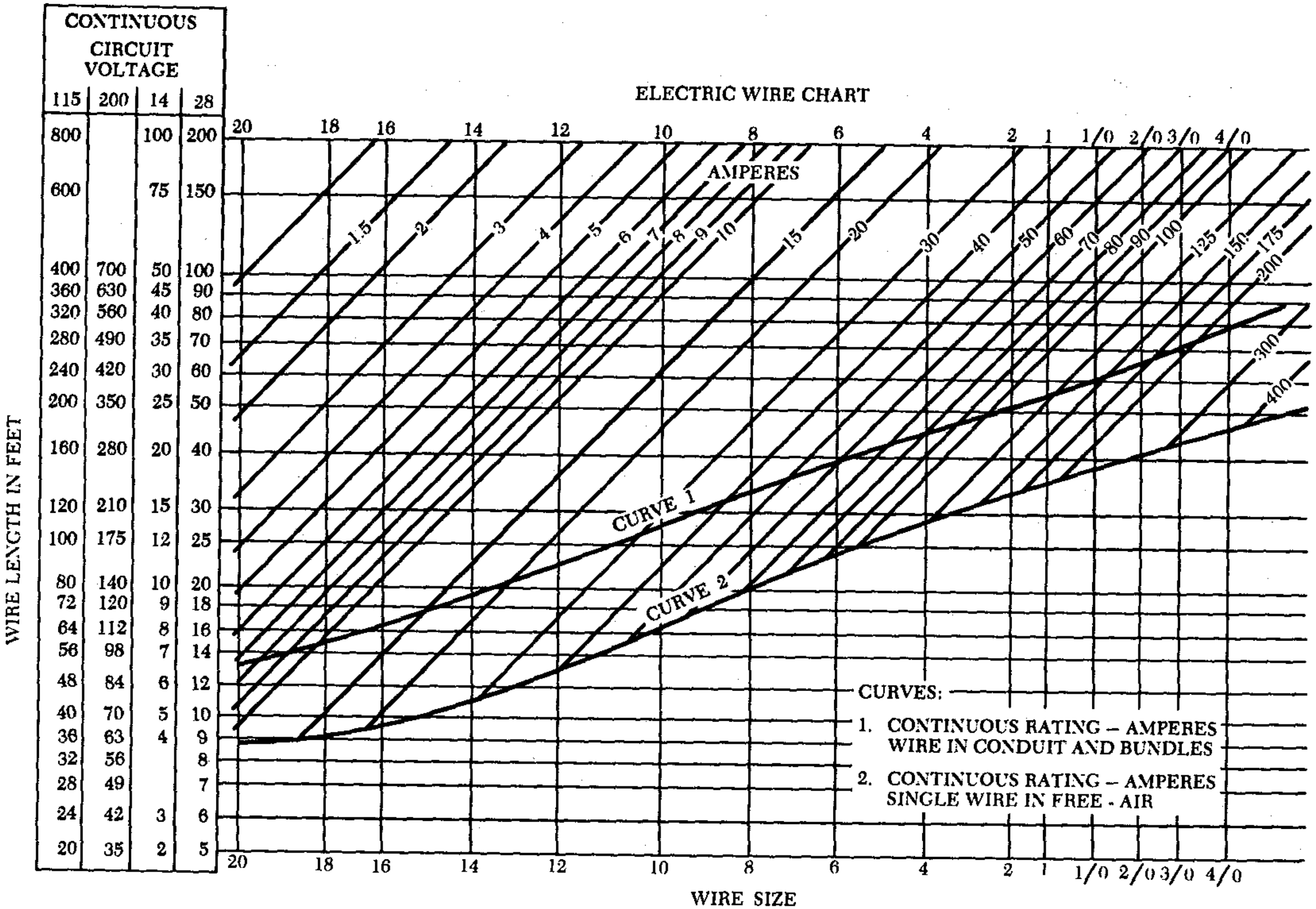


FIGURE 11-7. Conductor chart, continuous flow. (Applicable to copper conductors.)

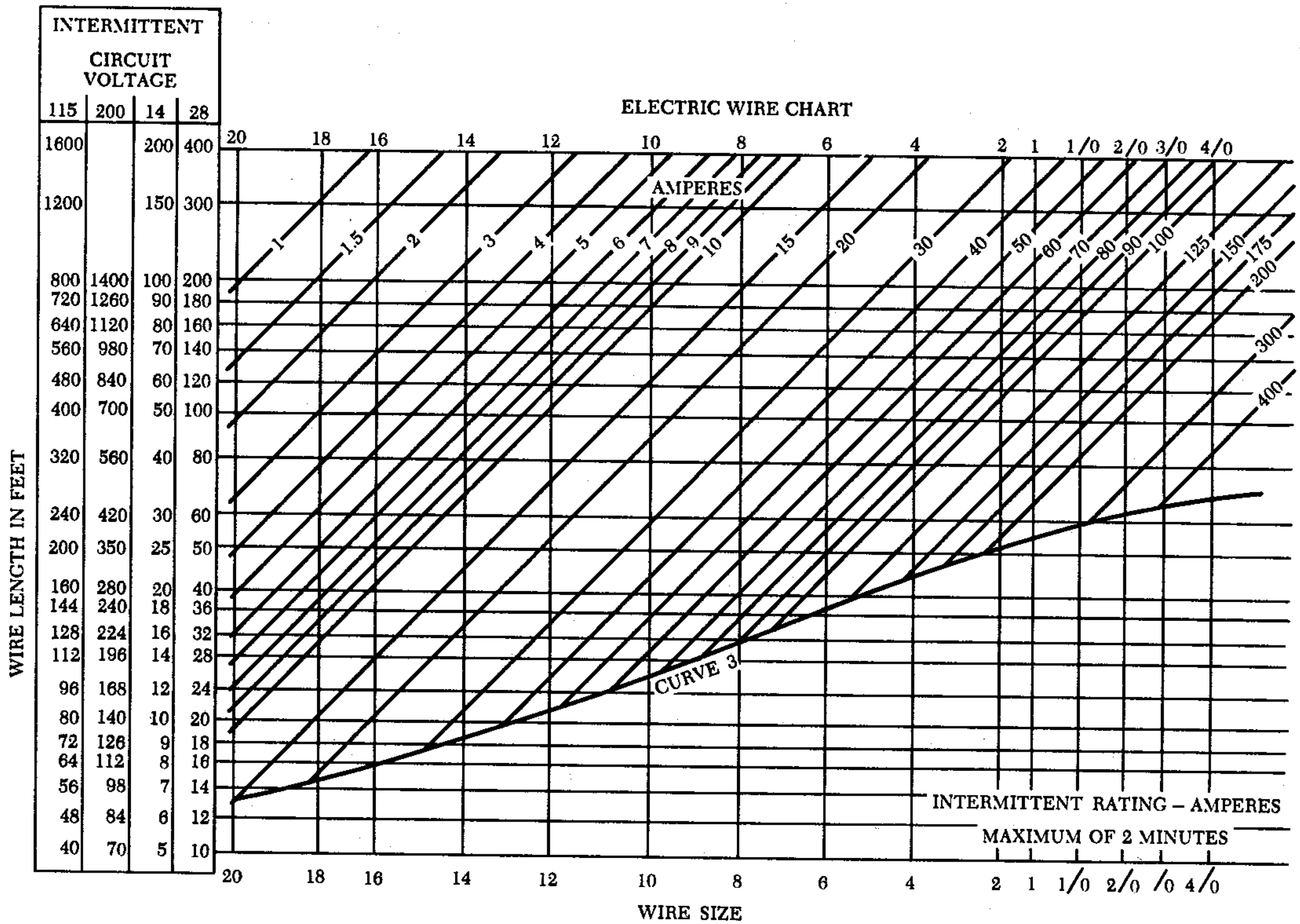


FIGURE 11–8. Conductor chart, intermittent flow.

(1) The conductor length in feet.

(2) The number of amperes of current to be carried.

(3) The amount of voltage drop permitted.

(4) Whether the current to be carried will be intermittent or continuous, and if continuous, whether it is a single conductor in free air, in a conduit, or in a bundle.

Assume that it is desired to install a 50-ft. conductor from the aircraft bus to the equipment in a 28-volt system. For this length, a 1-volt drop is permissible for continuous operation. By referring to the chart in figure 11–7, the maximum number of feet a conductor may be run carrying a specified current with a 1–volt drop can be determined. In this example the number 50 is selected.

Assuming the current required by the equipment is 20 amperes, the line indicating the value of 20 amperes should be selected from the diagonal lines. Follow this diagonal line downward until it intersects the horizontal line number 50. From this point, drop straight downward to the bottom of the chart to find that a conductor between size No. 8 and No. 10 is required to prevent a greater drop than 1 volt. Since the indicated value is between two numbers, the larger size, No. 8, should be selected. This is the smallest size conductor which should be used to avoid an excessive voltage drop.

To determine that the conductor size is sufficient to preclude overheating, disregard both the numbers along the left side of the chart and the horizontal lines. Assume that the conductor is to be a single wire in free air carrying continuous current. Place a pointer at the top of the chart on the diagonal line numbered 20 amperes. Follow this line until the pointer intersects the diagonal line marked "curve 2." Drop the pointer straight downward to the bottom of the chart. This point is between numbers 16 and 18. The larger size, No. 16, should be selected. This is the smallest size conductor acceptable for carrying 20-ampere current in a single wire in free air without overheating.

If the installation is for equipment having only an intermittent (max. 2 min.) requirement for power, the chart in figure 11–8 is used in the same manner.

Conductor Insulation

Two fundamental properties of insulation materials (for example, rubber, glass, asbestos, or plastic) are insulation resistance and dielectric strength. These are entirely different and distinct properties.

Insulation resistance is the resistance to current leakage through and over the surface of insulation materials. Insulation resistance can be measured with a megger without damaging the insulation, and data so obtained serves as a useful guide in determining the general condition of the insulation. However, the data obtained in this manner may not give a true picture of the condition of the insulation. Clean, dry insulation having cracks or other faults might show a high value of insulation resistance but would not be suitable for use.

Dielectric strength is the ability of the insulator to withstand potential difference and is usually expressed in terms of the voltage at which the insulation fails because of the electrostatic stress. Maximum dielectric strength values can be measured by raising the voltage of a test sample until the insulation breaks down.

Because of the expense of insulation and its stiffening effect, together with the great variety of physical and electrical conditions under which the conductors are operated, only the necessary minimum insulation is applied for any particular type of cable designed to do a specific job.

The type of conductor insulation material varies with the type of installation. Such types of insulation as rubber, silk, and paper are no longer used extensively in aircraft systems. More common today are such materials as vinyl, cotton, nylon, Teflon, and Rockbestos.

Identifying Wire and Cable

Aircraft electrical system wiring and cable may be marked with a combination of letters and numbers to identify the wire, the circuit it belongs to, the gage number, and other information necessary to relate the wire or cable to a wiring diagram. Such markings are called the identification code.

There is no standard procedure for marking and identifying wiring; each manufacturer normally develops his own identification code. One identification system (figure 11–9) shows the usual spacing in marking a wire. The number 22 in the code refers to the system in which the wire is installed, *e.g.*, the VHF system. The next set of numbers, .013, is the wire number, and the 18 indicates the wire size.

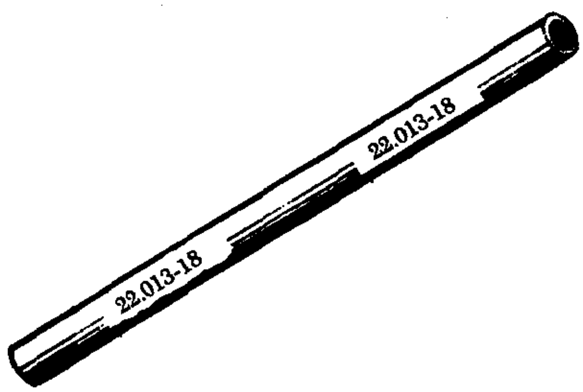


FIGURE 11-9. Wire identification code.

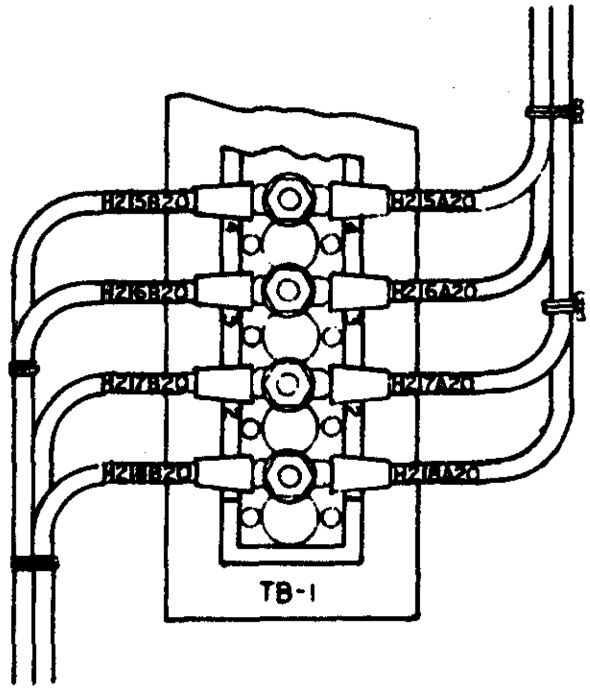


FIGURE 11-10. Wire identification at a terminal block.

Some system components, especially plugs and jacks, are identified by a letter or group of letters and numbers added to the basic identification number. These letters and numbers may indicate the location of the component in the system. Interconnected cables are also marked in some systems to indicate location, proper termination, and use.

In any system, the marking should be legible, and the stamping color should contrast with the color of the wire insulation. For example, black stamping should be used with light-colored backgrounds, or white stamping on dark-colored backgrounds.

Wires are usually marked at intervals of not more than 15 in. lengthwise and within 3 in. of each junction or terminating point. Figure 11-10 shows wire identification at a terminal block.

Coaxial cable and wires at terminal blocks and junction boxes are often identified by marking or stamping a wiring sleeve rather than the wire itself. For general purpose wiring, a flexible vinyl sleeving, either clear or white opaque, is commonly used. For high-temperature applications, silicone rubber or silicone fiber glass sleeving is recommended. Where resistance to synthetic hydraulic fluids or other solvents is necessary, either clear or white opaque nylon sleeving can be used.

While the preferred method is to stamp the identification marking directly on the wire or on the sleeving, other methods are often employed. Figure 11-11 shows two alternate methods: one method uses

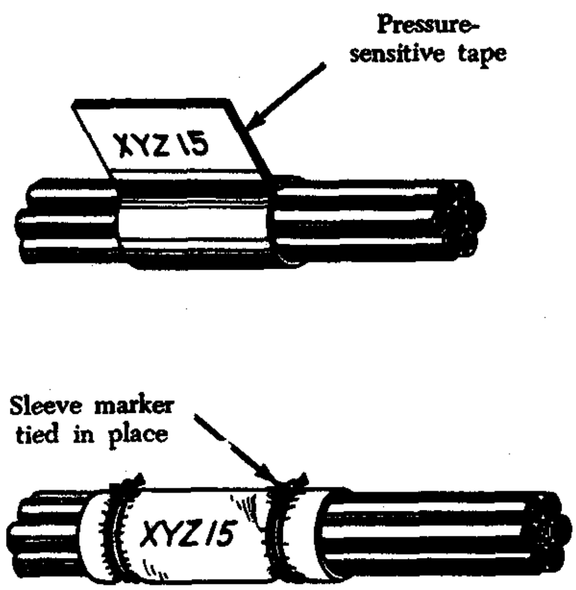


FIGURE 11-11. Alternate methods of identifying wire bundles.

a marked sleeve tied in place; the other uses a pressure-sensitive tape.

Electrical Wiring Installation

The following recommended procedures for installing aircraft electrical wiring are typical of those used on most aircraft. For purposes of this discussion, the following definitions are applicable:

(1) Open wiring—any wire, wire group, or wire bundle not enclosed in conduit.

(2) Wire group—two or more wires going to the same location tied together to retain identity of the group.

(3) Wire bundle—two or more wire groups tied together because they are going in the same direction at the point where the tie is located.

(4) Electrically protected wiring—wires which include (in the circuit) protection against overloading, such as fuses, circuit breakers, or other limiting devices.

(5) Electrically unprotected wiring—wires (generally from generators to main bus distribution points) which do not have protection, such as fuses, circuit breakers, or other current-limiting devices.

Wire Groups and Bundles

Grouping or bundling certain wires, such as electrically unprotected power wiring and wiring going to duplicate vital equipment, should be avoided.

Wire bundles should generally be less than 75 wires, or 1-1/2 to 2 in. in diameter where practicable. When several wires are grouped at junction boxes, terminal blocks, panels, etc., identity of the group within a bundle (figure 11-12) can be retained.

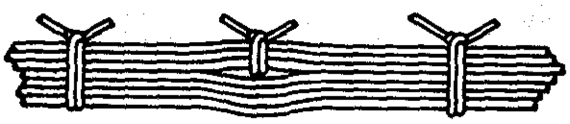


FIGURE 11-12. Group and bundle ties.

Twisting Wires

When specified on the engineering drawing, or when accomplished as a local practice, parallel wires must sometimes be twisted. The following are the most common examples:

(1) Wiring in the vicinity of magnetic compass or flux valve.

(2) Three-phase distribution wiring.

(3) Certain other wires (usually radio wiring) as specified on engineering drawings.

Twist the wires so that they will lie snugly against each other, making approximately the number of twists per foot as shown in figure 11-13. Always check wire insulation for damage after twisting. If the insulation is torn or frayed, replace the wire.

FIGURE 11-13. Recommended number of twists per foot.

	Wire Size									
	#22	#20	#18	#16	#14	#12	#10	#8	#6	#4
2 Wires	10	10	9	8	7½	7	6½	6	5	4
3 Wires	10	10	8½	7	6½	6	5½	5	4	3

Spliced Connections in Wire Bundles

Spliced connections in wire groups or bundles should be located so that they can be easily inspected. Splices should also be staggered (figure 11-14) so that the bundle does not become excessively enlarged. All noninsulated splices should be covered with plastic, securely tied at both ends.

Slack in Wiring Bundles

Single wires or wire bundles should not be installed with excessive slack. Slack between supports should normally not exceed a maximum of 1/2 in. deflection with normal hand force (figure 11-15). However, this may be exceeded if the wire bundle is thin and the clamps are far apart. Slack should never be so great that the wire bundle could abrade against any surface. A sufficient amount of slack should be allowed near each end of a bundle to:

(1) Permit easy maintenance.

(2) Allow replacement of terminals.

(3) Prevent mechanical strain on the wires, wire junctions, and supports.

(4) Permit free movement of shock and vibration-mounted equipment.

(5) Permit shifting of equipment for purposes of maintenance.

Bend Radii

Bends in wire groups or bundles should be not less than 10 times the outside diameter of the wire group or bundle. However, at terminal strips, where wire is suitably supported at each end of the bend, a minimum radius of three times the outside diameter of the wire, or wire bundle, is normally acceptable. There are, of course, exceptions to these guidelines in the case of certain types of cable; for

FIGURE 11–14. Staggered splices in a wire bundle.

example, coaxial cable should never be bent to a smaller radius than ten times the outside diameter.

Routing and Installations

All wiring should be installed so that it is mechanically and electrically sound and neat in appearance. Whenever practicable, wires and bundles should be routed parallel with, or at right angles to, the stringers or ribs of the area involved. An exception to this general rule is coaxial cable, which is routed as directly as possible.

The wiring must be adequately supported throughout its length. A sufficient number of supports must be provided to prevent undue vibration of the unsupported lengths. All wires and wire groups should be routed and installed to protect them from:

(1) Chafing or abrasion.
(2) High temperature.
(3) Being used as handholds, or as support for personal belongings and equipment.
(4) Damage by personnel moving within the aircraft.
(5) Damage from cargo stowage or shifting.
(6) Damage from battery acid fumes, spray, or spillage.
(7) Damage from solvents and fluids.

Protection Against Chafing

Wires and wire groups should be protected against chafing or abrasion in those locations where contact with sharp surfaces or other wires would damage the insulation. Damage to the insulation can cause short circuits, malfunction, or inadvertent operation of equipment. Cable clamps should be used to support wire bundles at each hole through a bulkhead (figure 11–16). If wires come closer than 1/4 in. to the edge of the hole, a suitable grommet is used in the hole as shown in figure 11–17.

Sometimes it is necessary to cut nylon or rubber grommets to facilitate installation. In these instances, after insertion, the grommet can be secured in place with general-purpose cement. The cut should be at the top of the hole, and made at an angle of 45° to the axis of the wire bundle hole.

Protection against High Temperature

To prevent insulation deterioration, wires should be kept separate from high-temperature equipment, such as resistors, exhaust stacks, or heating ducts. The amount of separation is normally specified by engineering drawings. Some wires must invariably be run through hot areas. These wires must be insulated with high-temperature material such as asbestos, fiber glass, or Teflon. Additional protection is also often requred in the form of conduits. A low-temperature insulation wire should never be used to replace a high-temperature insulation wire.

Many coaxial cables have soft plastic insulation, such as polyethylene, which is especially subject to deformation and deterioration at elevated temperatures. All high-temperature areas should be avoided when installing these cables insulated with plastic or polyethylene.

Additional abrasion protection should be given to asbestos wires enclosed in conduit. Either conduit with a high-temperature rubber liner should be used, or asbestos wires can be enclosed individually in high-temperature plastic tubes before being installed in the conduit.

Protection Against Solvents and Fluids

Wires should not be installed in areas where they will be subjected to damage from fluids or in the lowest 4 in. of an aircraft fuselage, except those that must terminate in that area. If there is a possibility that wire may be soaked with fluids, plastic tubing should be used to protect the wire. This tubing should extend past the exposure area in both directions and should be tied at each end. If the wire has a low point between the tubing ends, provide a ⅛-in. drain hole, as shown in figure 11–18. This hole should be punched into the tubing after the installation is complete and the low point definitely established by using a hole punch to cut a half circle. Care should be taken not to damage any wires inside the tubing when using the punch.

Wire should never be routed below an aircraft

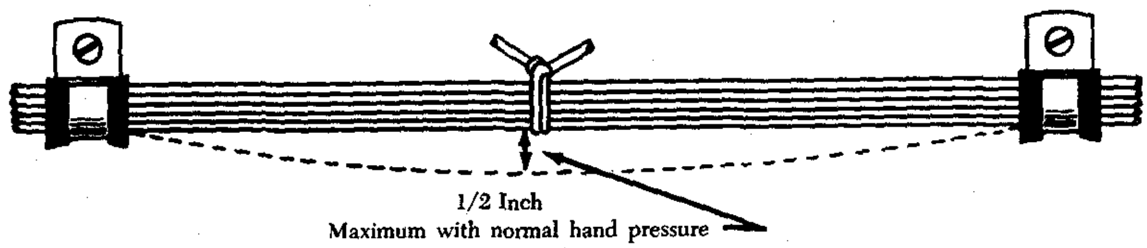


FIGURE 11-15. Slack in wire bundle between supports.

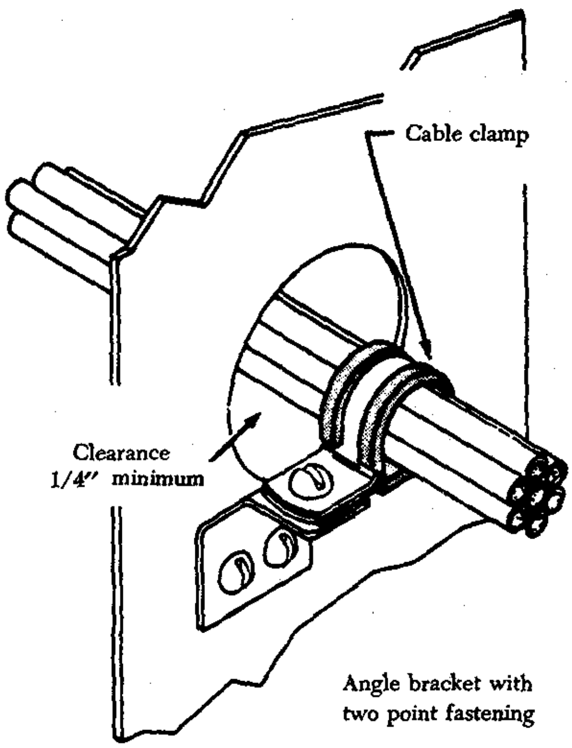


FIGURE 11-16. Cable clamp at bulkhead hole.

Routing Precautions

When wiring must be routed parallel to combustible fluid or oxygen lines for short distances, as much fixed separation as possible should be maintained. The wires should be on a level with, or above, the plumbing lines. Clamps should be spaced so that if a wire is broken at a clamp it will not contact the line. Where a 6-in. separation is not possible, both the wire bundle and the plumbing line can be clamped to the same structure to prevent any relative motion. If the separation is less than 2 in. but more than 1/2 in., a polyethylene sleeve may be used over the wire bundle to give further protection. Also two cable clamps back-to-back, as shown in figure 11-19, can be used to maintain a rigid separation only, and not for support of the bundle. No wire should be routed so that it is located nearer than 1/2 in. to a plumbing line. Neither should a wire or wire bundle be supported from a battery. All wires in the vicinity of an aircraft battery should be inspected frequently and wires discolored by battery fumes should be replaced.

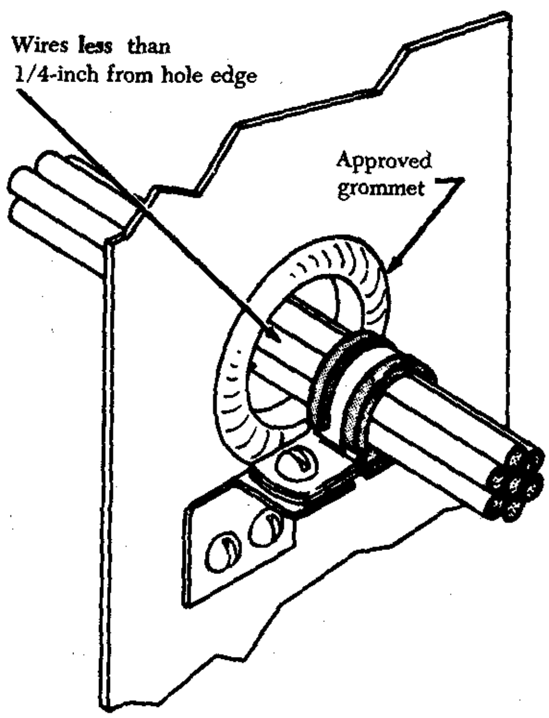
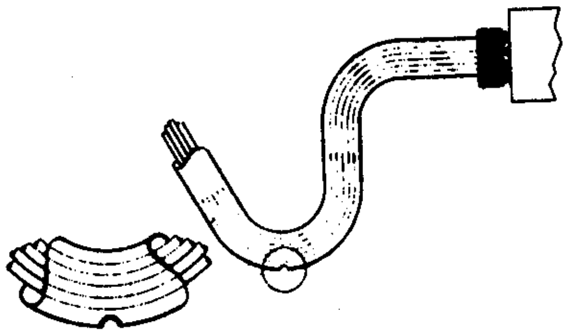


FIGURE 11-17. Cable clamp and grommet at bulkhead hole.

Protection of Wires in Wheel Well Area

Wires located in wheel wells are subject to many additional hazards, such as exposure to fluids, pinching, and severe flexing in service. All wire bundles should be protected by sleeves of flexible tubing securely held at each end, and there should be no relative movement at points where flexible tubing is secured. These wires and the insulating tubing should be inspected carefully at frequent intervals, and wires or tubing should be replaced at the first sign of wear. There should be no strain on attachments when parts are fully extended, but slack should not be excessive.



Drainage hole 1/8-inch diameter at
lowest point in tubing. Make the
hole after installation is complete
and lowest point is firmly established

FIGURE 11-18. Drain hole in low point of tubing.

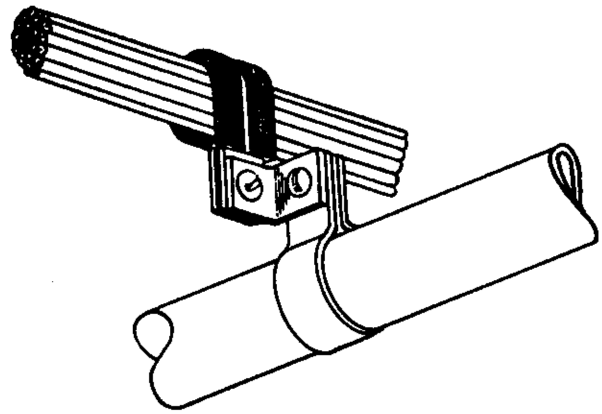


FIGURE 11-19. Separation of wires from plumbing lines.

plumbing line that carries flammable fluids or oxygen.

Wiring should be routed to maintain a minimum clearance of at least 3 in. from control cables. If this cannot be accomplished, mechanical guards should be installed to prevent contact between wiring and control cables.

Installation of Cable Clamps

Cable clamps should be installed with regard to the proper angle, as shown in figure 11–20. The mounting screw should be above the wire bundle. It is also desirable that the back of the cable clamp rest against a structural member where practicable.

Figure 11–21 shows some typical mounting hardware used in installing cable clamps.

Care should be taken that wires are not pinched in cable clamps. Where possible, mount the cables directly to structural members, as shown in figure 11–22.

Clamps can be used with rubber cushions to secure wire bundles to tubular structures as shown in figure 11–23. Such clamps must fit tightly, but should not be deformed when locked in place.

LACING AND TYING WIRE BUNDLES

Wire groups and bundles are laced or tied with cord to provide ease of installation, maintenance, and inspection. This section describes and illustrates recommended procedures for lacing and tying wires with knots which will hold tightly under all conditions. For the purposes of this discussion, the following terms are defined:

(1) Tying is the securing together of a group or bundle of wires by individual pieces of cord tied around the group or bundle at regular intervals.

(2) Lacing is the securing together of a group or bundle of wires by a continuous piece of cord forming loops at regular intervals around the group or bundle.

(3) A wire group is two or more wires tied or laced together to give identity to an individual system.

(4) A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.

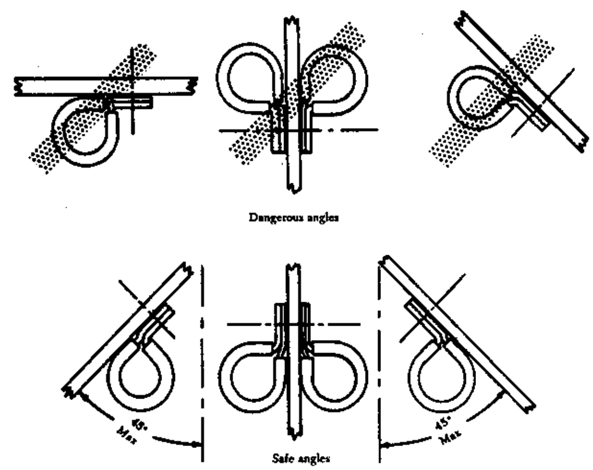


FIGURE 11-20. Proper mounting angles for cable clamps.

The material used for lacing and tying is either cotton or nylon cord. Nylon cord is moisture- and fungus-resistant, but cotton cord must be waxed before using to give it these necessary protective characteristics.

Single-Cord Lacing

Figure 11–24 shows the step in lacing a wire bundle with a single cord. The lacing procedure is started at the thick end of the wire group or bundle with a knot consisting of a clove hitch with an extra loop. The lacing is then continued at regular intervals with half hitches along the wire group or bundle and at each point where a wire or wire group branches off. The half hitches should be spaced so that the bundle is neat and secure. The lacing is ended by tying a knot consisting of a clove hitch with an extra loop. After the knot is tied, the free ends of the lacing cord should be trimmed to approximately 3/8 in.

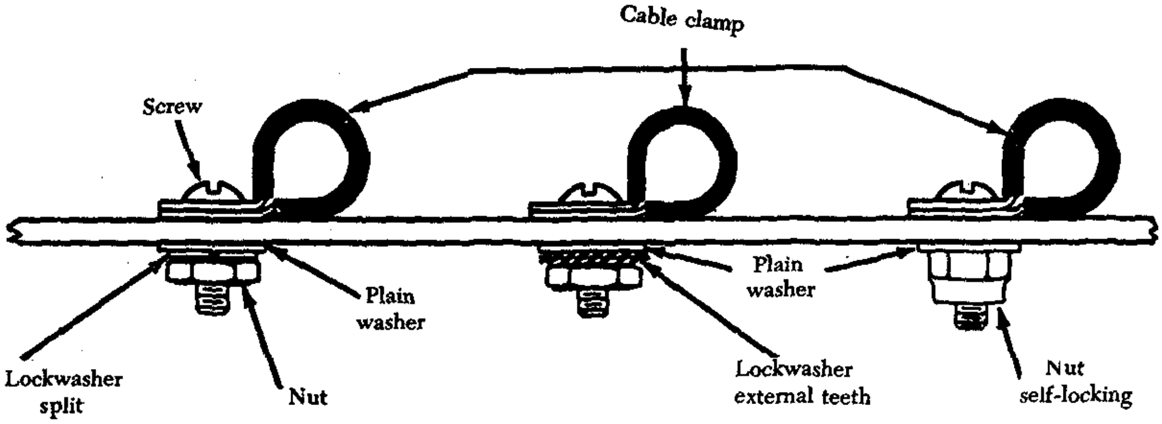


FIGURE 11–21. Typical mounting hardware for cable clamps.

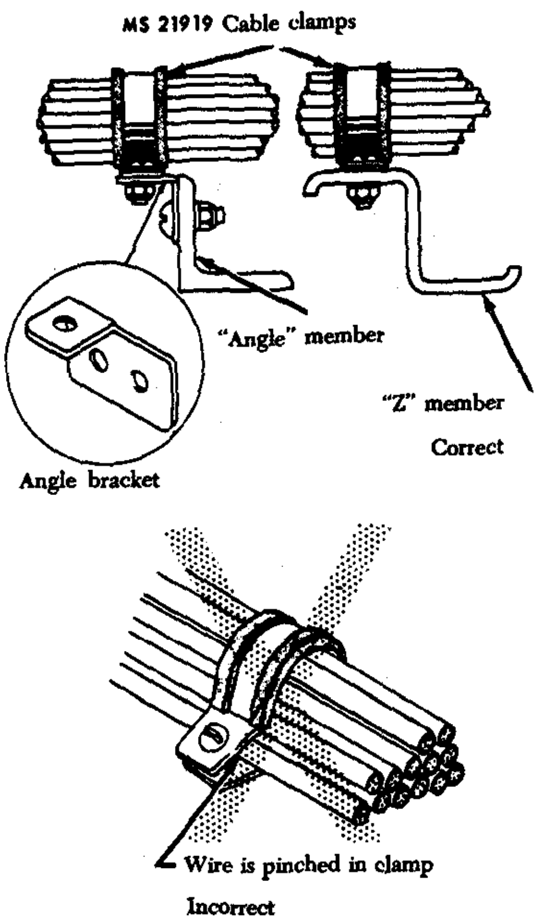


FIGURE 11–22. Mounting cable clamp to structure.

Double-Cord Lacing

Figure 11–25 illustrates the procedure for dou-

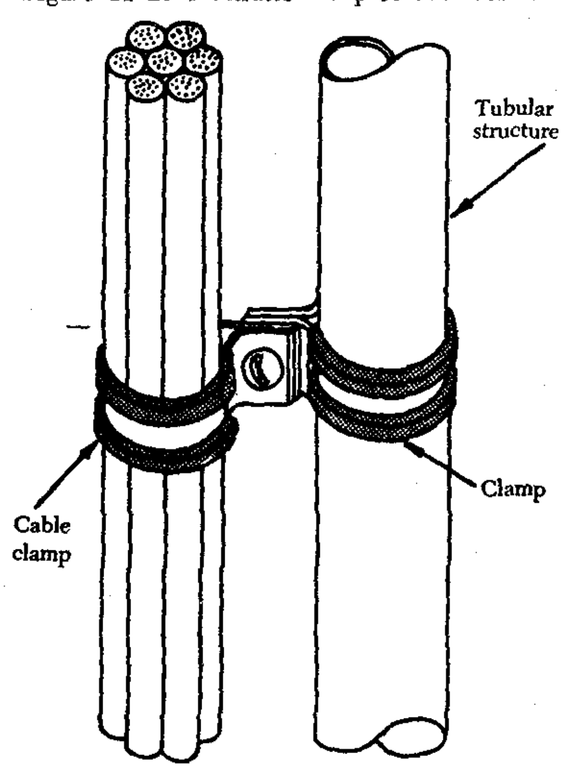


FIGURE 11–23. Installing cable clamp to tubular structure.

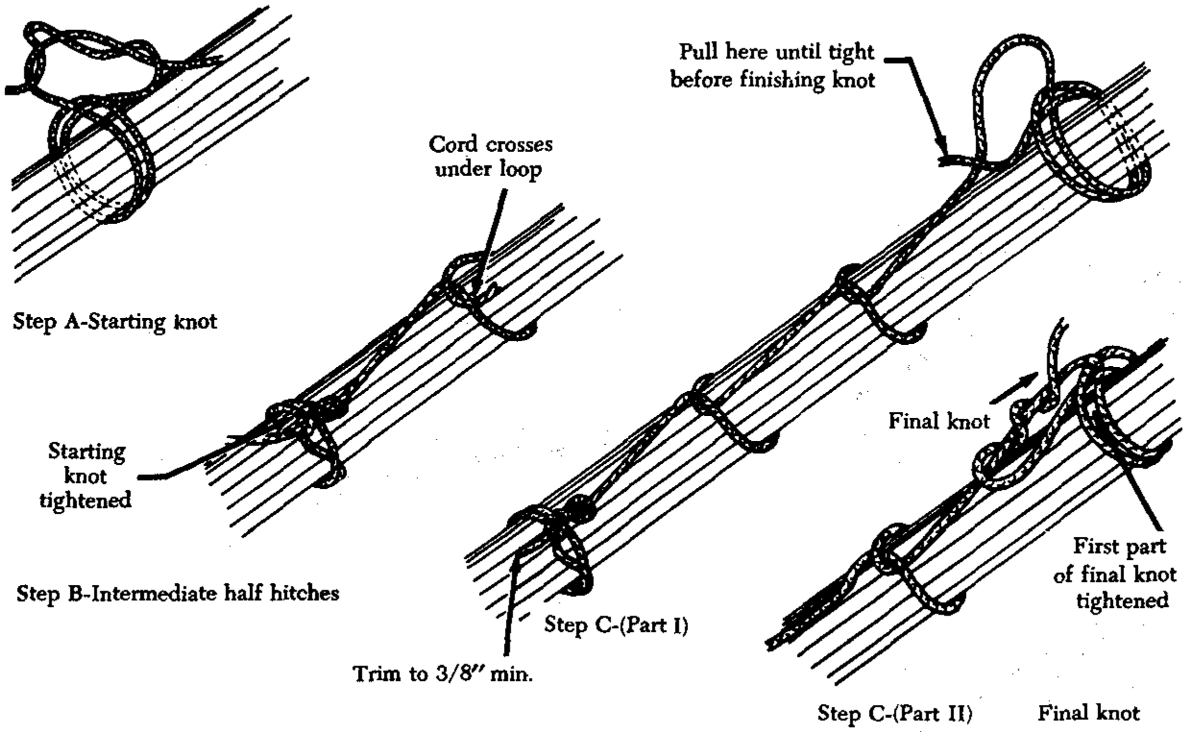


FIGURE 11-24. Single-cord lacing.

ble-cord lacing. The lacing is started at the thick end of the wire group or bundle with a bowline-on-a-bight knot (A of figure 11-25). At regular intervals along the wire group or bundle, and at each point where a wire branches off, the lacing is continued using half hitches, with both cords held firmly together. The half hitches should be spaced so that the group or bundle is neat and secure. The lacing is ended with a knot consisting of a half hitch, continuing one of the cords clockwise and the other counterclockwise and then tying the cord ends with a square knot. The free ends of the lacing cord should be trimmed to approximately 3/8 in.

Lacing Branch-Offs

Figure 11-26 illustrates a recommended procedure for lacing a wire group that branches off the main wire bundle. The branch-off lacing is started with a knot located on the main bundle just past the branch-off point. Continue the lacing along the branched-off wire group, using regularly spaced half hitches. If a double cord is used, both cords should be held snugly together. The half hitches should be spaced to lace the bundle neatly and securely. The lacing is ended with the regular terminal knot used in single- or double-cord lacing. The free ends of the lacing cord should be neatly trimmed.

Tying

All wire groups or bundles should be tied where supports are more than 12 in. apart. Figure 11-28 illustrates a recommended procedure for tying a wire group or bundle. The tie is started by wrapping the cord around the wire group to tie a clove-hitch knot. Then a square knot with an extra loop is tied, and the free ends of the cord are trimmed.

Temporary ties are sometimes used in making up and installing wire groups and bundles. Colored cord is normally used to make temporary ties, since they are removed when the installation is complete.

Whether laced or tied, bundles should be secured to prevent slipping, but not so tightly that the cord cuts into or deforms the insulation. This applies especially to coaxial cable, which has a soft dielectric insulation between the inner and outer conductor.

The part of a wire group or bundle located inside a conduit is not tied or laced, but wire groups or bundles inside enclosures, such as junction boxes, should be laced only.

CUTTING WIRE AND CABLE

To make installation, maintenance, and repair easier, wire and cable runs in aircraft are broken at specified locations by junctions, such as connectors,

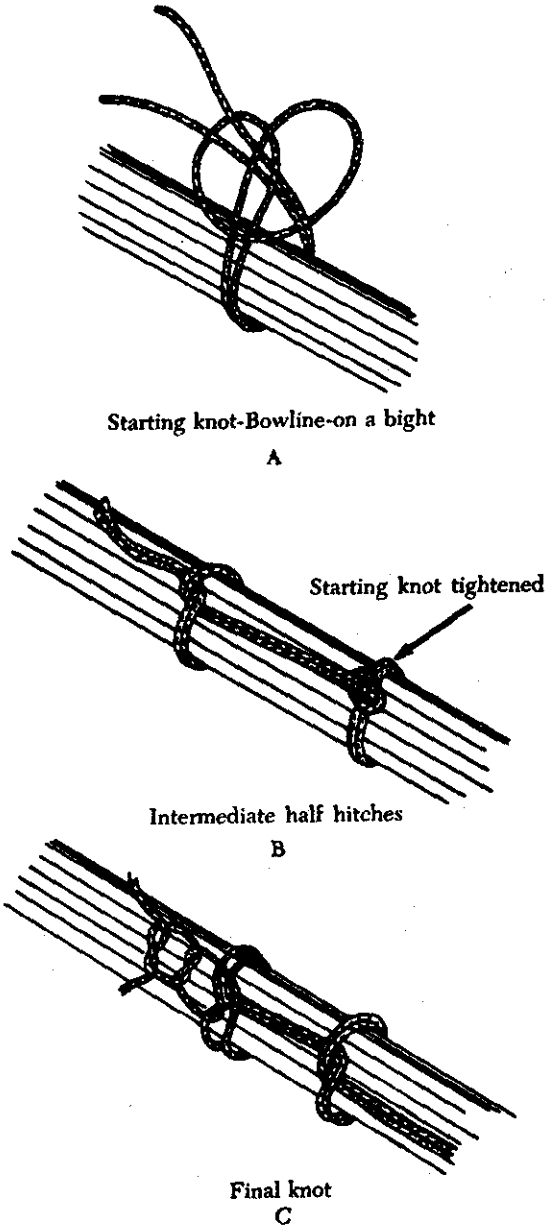


FIGURE 11-25. Double-cord lacing.

terminal blocks, or buses. Before assembly to these junctions, wires and cables must be cut to length.

All wires and cables should be cut to the lengths specified on drawings and wiring diagrams. The cut should be made clean and square, and the wire or cable should not be deformed. If necessary, large-diameter wire should be re-shaped after cutting. Good cuts can be made only if the blades of cutting tools are sharp and free from nicks. A dull blade will deform and extrude wire ends.

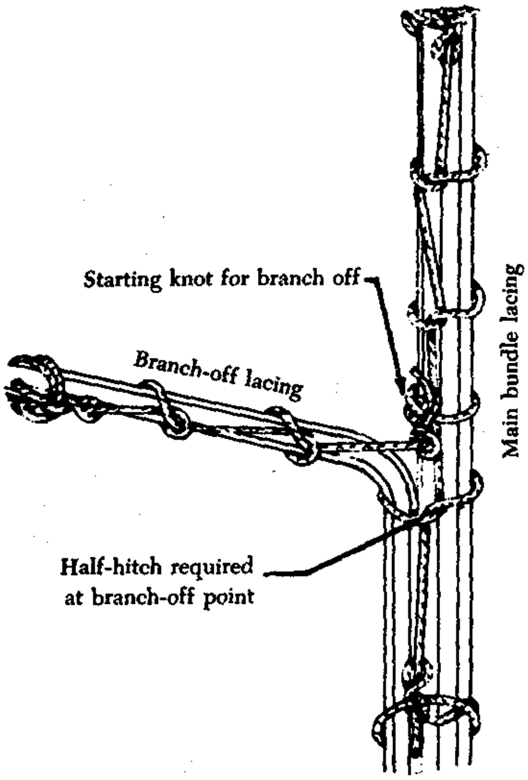


FIGURE 11-26. Lacing a branch-off.

Stripping Wire and Cable

Before wire can be assembled to connectors, terminals, splices, etc., the insulation must be stripped from connecting ends to expose the bare conductor.

Copper wire can be stripped in a number of ways depending on the size and insulation. Figure 11-27 lists some types of stripping tools recommended for various wire sizes and types of insulation.

FIGURE 11-27. Wire strippers for copper wire.

Stripper	*Wire Size*	*Insulations*
Hot-blade	#26—#4	All except asbestos
Rotary, electric	#26—#4	All
Bench	#20—#6	All
Hand pliers	#26—#8	All
Knife	#2 —#0000	All

Aluminum wire must be stripped very carefully, using extreme care, since individual strands will break very easily after being nicked.

The following general precautions are recommended when stripping any type of wire:

(1) When using any type of wire stripper, hold the wire so that it is perpendicular to cutting blades.

(2) Adjust automatic stripping tools care-

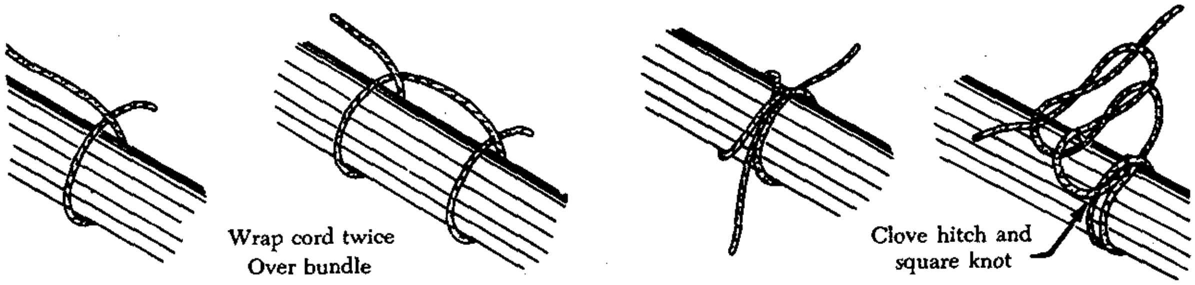


FIGURE 11-28. Tying a wire group or bundle.

fully; follow the manufacturer's instructions to avoid nicking, cutting, or otherwise damaging strands. This is especially important for aluminum wires and for copper wires smaller than No. 10. Examine stripped wires for damage. Cut off and re-strip (if length is sufficient), or reject and replace any wires having more than the allowable number of nicked or broken strands listed in the manufacturer's instructions.

(3) Make sure insulation is clean-cut with no frayed or ragged edges. Trim if necessary.

(4) Make sure all insulation is removed from stripped area. Some types of wires are supplied with a transparent layer of insulation between the conductor and the primary insulation. If this is present, remove it.

(5) When using hand-plier strippers to remove lengths of insulation longer than 3/4 in., it is easier to accomplish in two or more operations.

(6) Re-twist copper strands by hand or with pliers, if necessary, to restore natural lay and tightness of strands.

A pair of hand wire strippers is shown in figure 11-29. This tool is commonly used to strip most types of wire.

The following general procedures describe the steps for stripping wire with a hand stripper. (Refer to figure 11-30.)

(1) Insert wire into exact center of correct cutting slot for wire size to be stripped. Each slot is marked with wire size.

(2) Close handles together as far as they will go.

(3) Release handles, allowing wire holder to return to the "open" position.

(4) Remove stripped wire.

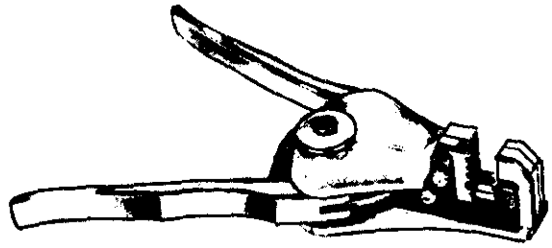


FIGURE 11-29. Light-duty hand wire strippers.

Solderless Terminals and Splices

Splicing of electrical cable should be kept to a minimum and avoided entirely in locations subject to extreme vibrations. Individual wires in a group or bundle can usually be spliced, provided the completed splice is located so that it can be inspected periodically. Splices should be staggered so that the bundle does not become excessively enlarged. Many types of aircraft splice connectors are available for splicing individual wires. Self-insulated splice connectors are usually preferred; however, a noninsulated splice connector can be used if the splice is covered with plastic sleeving secured at both ends. Solder splices may be used, but they are particularly brittle and not recommended.

Electric wires are terminated with solderless terminal lugs to permit easy and efficient connection to and disconnection from terminal blocks, bus bars, or other electrical equipment. Solderless splices join electric wires to form permanent continuous runs. Solderless terminal lugs and splices are made of copper or aluminum and are preinsulated or uninsulated, depending on the desired application.

Terminal lugs are generally available in three types for use in different space conditions. These are the flag, straight, and right-angle lugs. Terminal lugs are "crimped" (sometimes called "staked" or "swaged") to the wires by means of hand or power crimping tools.

The following discussion describes recommended

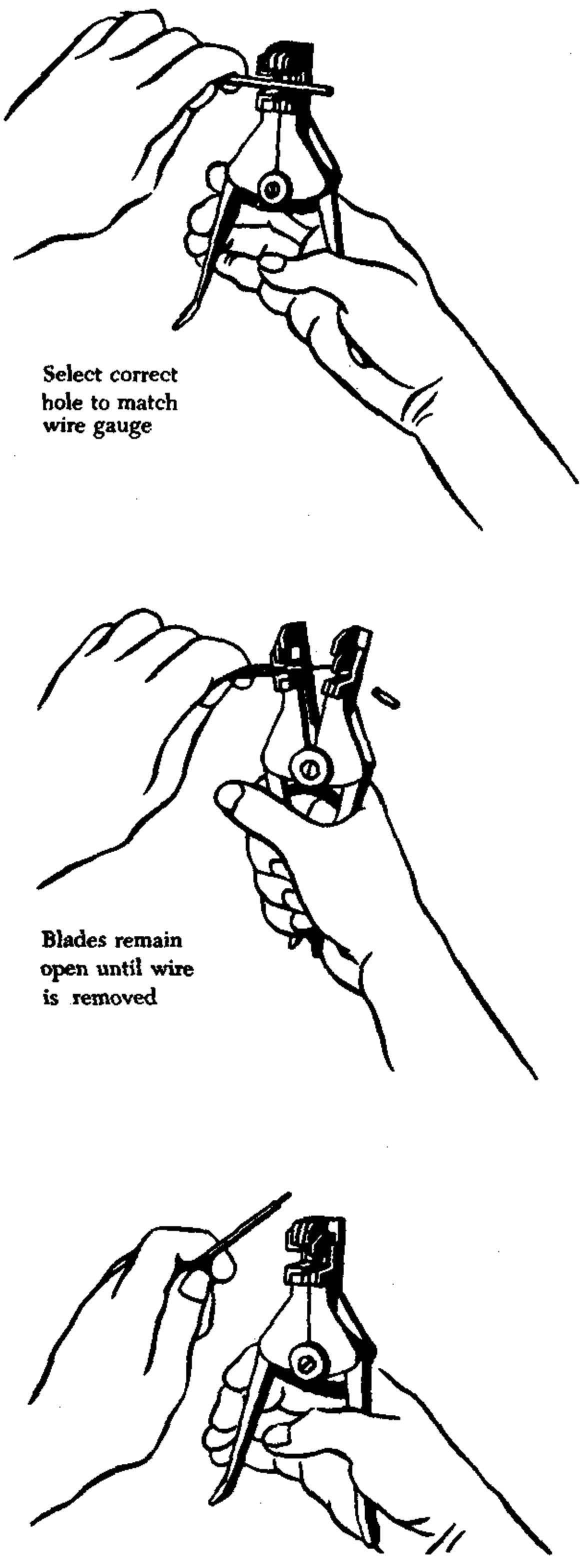


FIGURE 11-30. Stripping wire with hand stripper.

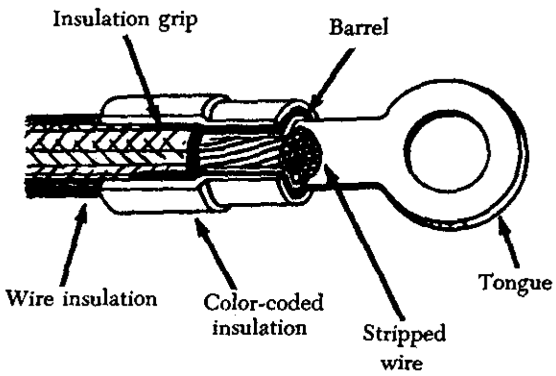


FIGURE 11-31. Preinsulated terminal lug.

methods for terminating copper and aluminum wires using solderless terminal lugs. It also describes the method for splicing copper wires using solderless splices.

Copper Wire Terminals

Copper wires are terminated with solderless, preinsulated straight copper terminal lugs. The insulation is part of the terminal lug and extends beyond its barrel so that it will cover a portion of the wire insulation, making the use of an insulation sleeve unnecessary (figure 11-31).

In addition, preinsulated terminal lugs contain an insulation grip (a metal reinforcing sleeve) beneath the insulation for extra gripping strength on the wire insulation. Preinsulated terminals accommodate more than one size of wire; the insulation is usually color-coded to identify the wire sizes that can be terminated with each of the terminal lug sizes.

Crimping Tools

Hand, portable power, and stationary power tools are available for crimping terminal lugs. These tools crimp the barrel of the terminal lug to the conductor and simultaneously crimp the insulation grip to the wire insulation.

Hand crimping tools all have a self-locking ratchet that prevents opening the tool until the crimp is complete. Some hand crimping tools are equipped with a nest of various size inserts to fit different size terminal lugs. Others are used on one terminal lug size only. All types of hand crimping tools are checked by gages for proper adjustment of crimping jaws.

Figure 11-32 shows a terminal lug inserted into a hand tool. The following general guidelines outline the crimping procedure.

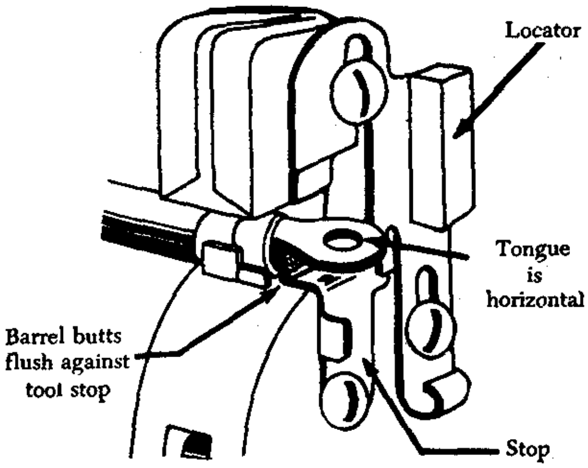


FIGURE 11-32. Inserting terminal lug into hand tool.

(1) Strip the wire insulation to proper length.
(2) Insert the terminal lug, tongue first, into hand tool barrel crimping jaws until the terminal lug barrel butts flush against the tool stop.
(3) Insert the stripped wire into the terminal lug barrel until the wire insulation butts flush against the end of the barrel.
(4) Squeeze the tool handles until the ratchet releases.
(5) Remove the completed assembly and examine it for proper crimp.

Some types of uninsulated terminal lugs are insulated after assembly to a wire by means of pieces of transparent flexible tubing called "sleeves." The sleeve provides electrical and mechanical protection at the connection. When the size of the sleeving used is such that it will fit tightly over the terminal lug, the sleeving need not be tied; otherwise, it should be tied with lacing cord as illustrated in figure 11-33.

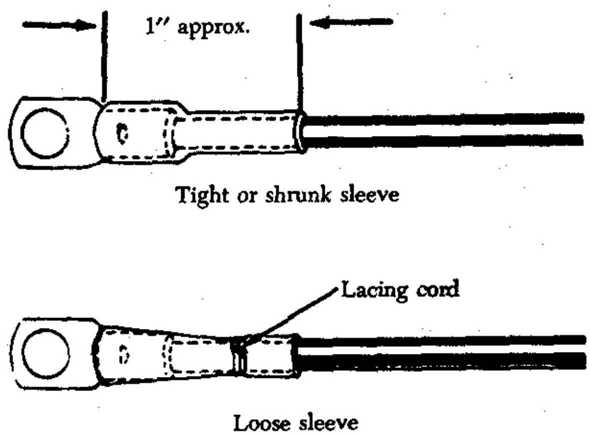


FIGURE 11-33. Insulating sleeve.

Aluminum Wire Terminals

The use of aluminum wire in aircraft systems is increasing because of its weight advantage over copper. However, bending aluminum will cause "work hardening" of the metal, making it brittle. This results in failure or breakage of strands much sooner than in a similar case with copper wire. Aluminum also forms a high-resistant oxide film immediately upon exposure to air. To compensate for these disadvantages, it is important to use the most reliable installation procedures.

Only aluminum terminal lugs are used to terminate aluminum wires. They are generally available in three types: (1) Straight, (2) right-angle, and (3) flag. All aluminum terminals incorporate an inspection hole (figure 11-34) which permits checking the depth of wire insertion. The barrel of aluminum terminal lugs is filled with a petrolatum-zinc dust compound. This compound removes the oxide film from the aluminum by a grinding process during the crimping operation. The compound will also minimize later oxidation of the completed connection by excluding moisture and air. The compound is retained inside the terminal lug barrel by a plastic or foil seal at the end of the barrel.

Splicing Copper Wires Using Preinsulated Splices

Preinsulated permanent copper splices join small wires of sizes 22 through 10. Each splice size can be used for more than one wire size. Splices are usually color-coded in the same manner as preinsulated small copper terminal lugs. Some splices are insulated with white plastic. Splices are also used to reduce wire sizes (figure 11-35).

Crimping tools are used to accomplish this type of splice. The crimping procedures are the same as those used for terminal lugs, except that the crimping operation must be done twice, once for each end of the splice.

EMERGENCY SPLICING REPAIRS

Broken wires can be repaired by means of crimped splices, by using terminal lugs from which the tongue has been cut off, or by soldering together and potting broken strands. These repairs are applicable to copper wire. Damaged aluminum wire must not be temporarily spliced. These repairs are for temporary emergency use only and should be replaced as soon as possible with permanent repairs. Since some manufacturers prohibit splicing,

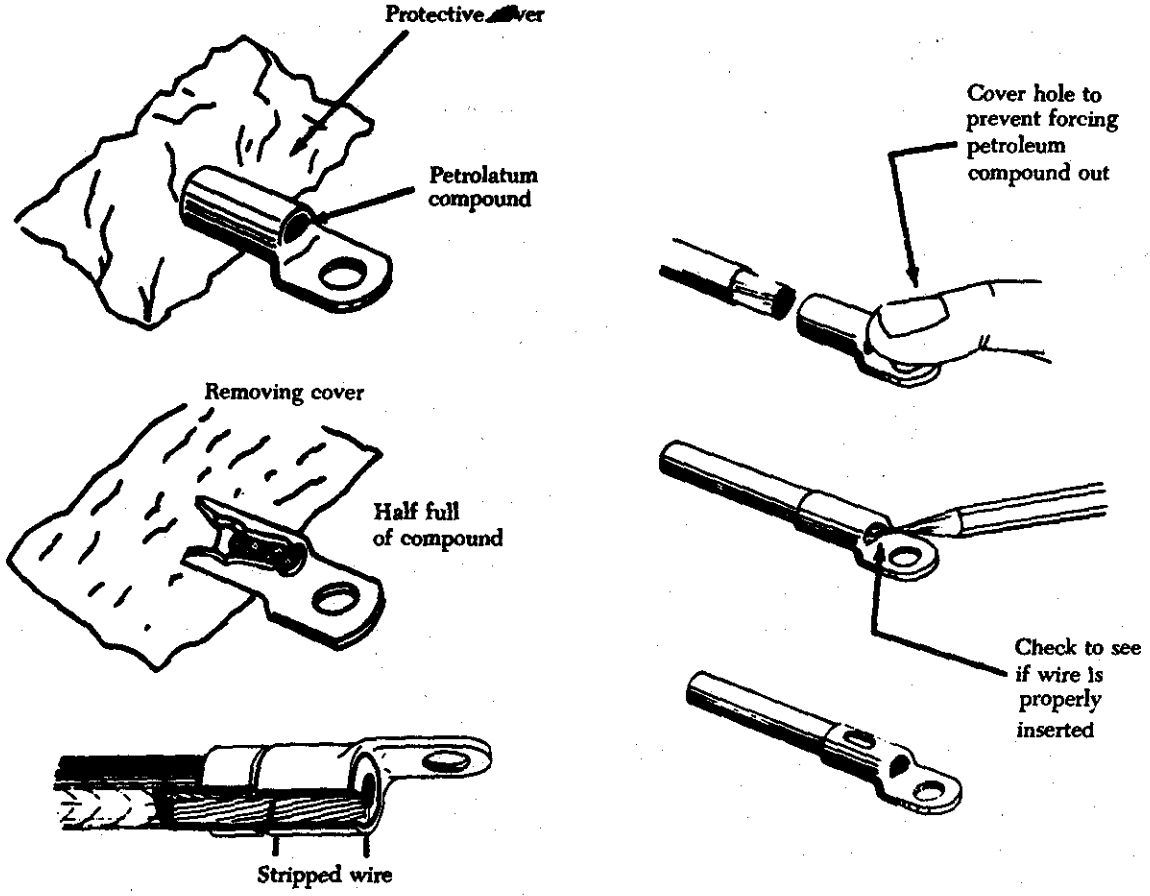


FIGURE 11-34. Inserting aluminum wire into aluminum terminal lugs.

the applicable manufacturer's instructions should always be consulted.

Splicing with Solder and Potting Compound

When neither a permanent splice nor a terminal lug is available, a broken wire can be repaired as follows (figure 11-36):

(1) Install a piece of plastic sleeving about 3 in. long, and of the proper diameter to fit loosely over the insulation, on one piece of the broken wire.

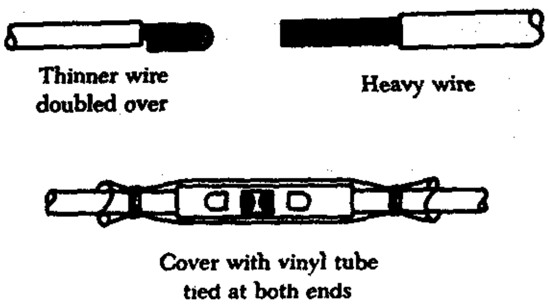


FIGURE 11-35. Reducing wire size with a permanent splice.

(2) Strip approximately 1-1/2 in. from each broken end of the wire.

(3) Lay the stripped ends side by side and twist one wire around the other with approximately four turns.

(4) Twist the free end of the second wire around the first wire with approximately four turns. Solder wire turns together, using 60/40 tin-lead resin-core solder.

(5) When solder is cool, draw the sleeve over the soldered wires and tie at one end. If potting compound is available, fill the sleeve with potting material and tie securely.

(6) Allow the potting compound to set without touching for 4 hrs. Full cure and electrical characteristics are achieved in 24 hrs.

CONNECTING TERMINAL LUGS TO TERMINAL BLOCKS

Terminal lugs should be installed on terminal blocks so that they are locked against movement in the direction of loosening (figure 11-37).

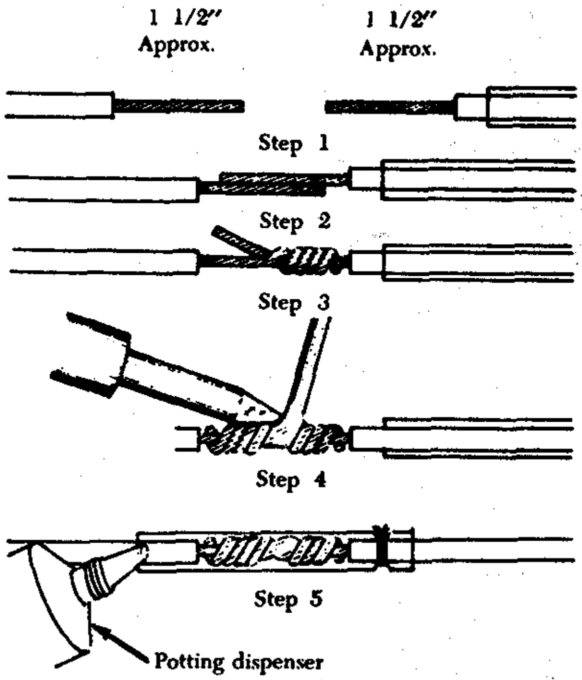


FIGURE 11-36. Repairing broken wire by soldering and potting.

Terminal blocks are normally supplied with studs secured in place by a plain washer, an external tooth lockwasher, and a nut. In connecting terminals, a recommended practice is to place copper terminal lugs directly on top of the nut, followed with a plain washer and elastic stop nut, or with a plain washer, split steel lockwasher, and plain nut.

Aluminum terminal lugs should be placed over a plated brass plain washer, followed with another plated brass plain washer, split steel lockwasher, and plain nut or elastic stop nut. The plated brass washer should have a diameter equal to the tongue width of the aluminum terminal lug. Consult the manufacturer's instructions for recommended dimensions of these plated brass washers. Do not place any washer in the current path between two aluminum terminal lugs or between two copper terminal lugs. Also, do not place a lockwasher directly against the tongue or pad of the aluminum terminal.

To join a copper terminal lug to an aluminum terminal lug, place a plated brass plain washer over the nut which holds the stud in place; follow with the aluminum terminal lug, a plated brass plain washer, the copper terminal lug, plain washer, split steel lockwasher, and plain nut or self-locking, all-metal nut. As a general rule use a torque wrench to tighten nuts to ensure sufficient contact pressure. Manufacturer's instructions provide installation torques for all types of terminals.

BONDING AND GROUNDING

Bonding is the electrical connecting of two or more conducting objects not otherwise adequately connected. Grounding is the electrical connecting of a conducting object to the primary structure for a return path for current. Primary structure is the main frame, fuselage, or wing structure of the aircraft, commonly referred to as ground. Bonding and grounding connections are made in aircraft electrical systems to:

(1) Protect aircraft and personnel against hazards from lightning discharge.
(2) Provide current return paths.
(3) Prevent development of radio-frequency potentials.
(4) Protect personnel from shock hazards.
(5) Provide stability of radio transmission and reception.
(6) Prevent accumulation of static charge.

General Bonding and Grounding Procedures

The following general procedures and precautions are recommended when making bonding or grounding connections:

(1) Bond or gronud parts to the primary aircraft structure where practicable.
(2) Make bonding or grounding connections so that no part of the aircraft structure is weakened.
(3) Bond parts individually if possible.
(4) Install bonding or grounding connections against smooth, clean surfaces.
(5) Install bonding or grounding connections so that vibration, expansion or contraction, or relative movement in normal service will not break or loosen the connection.

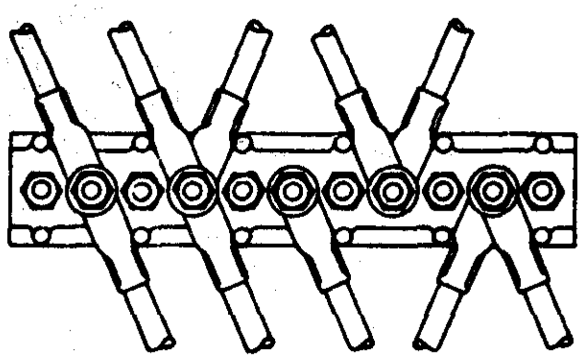
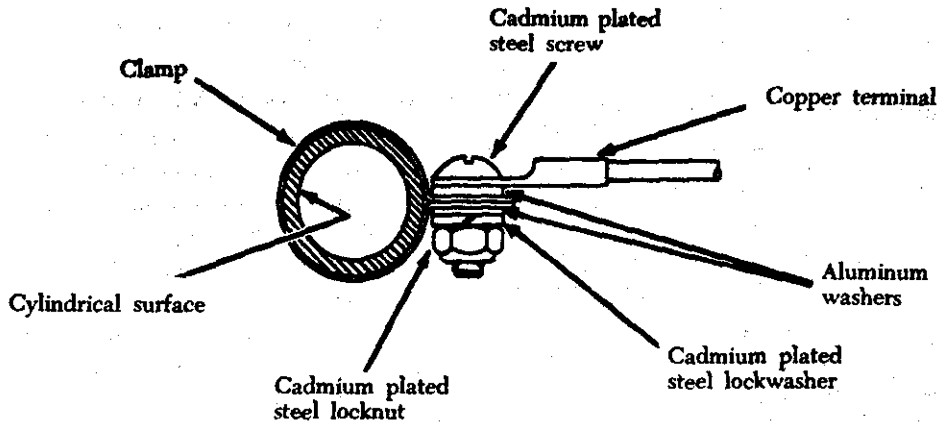
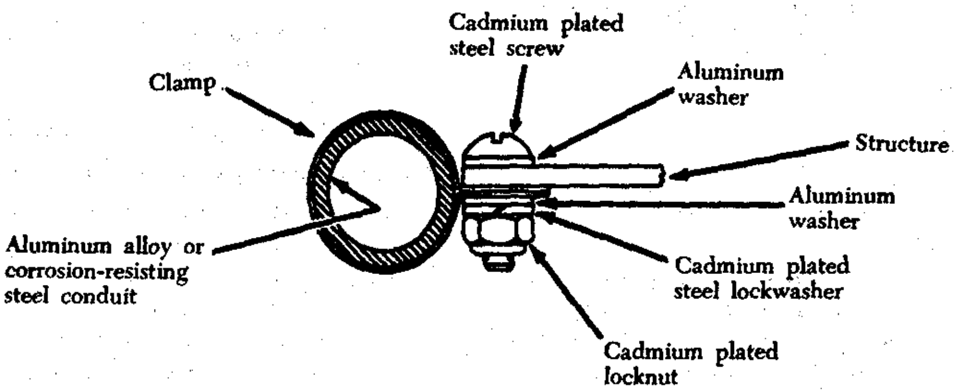


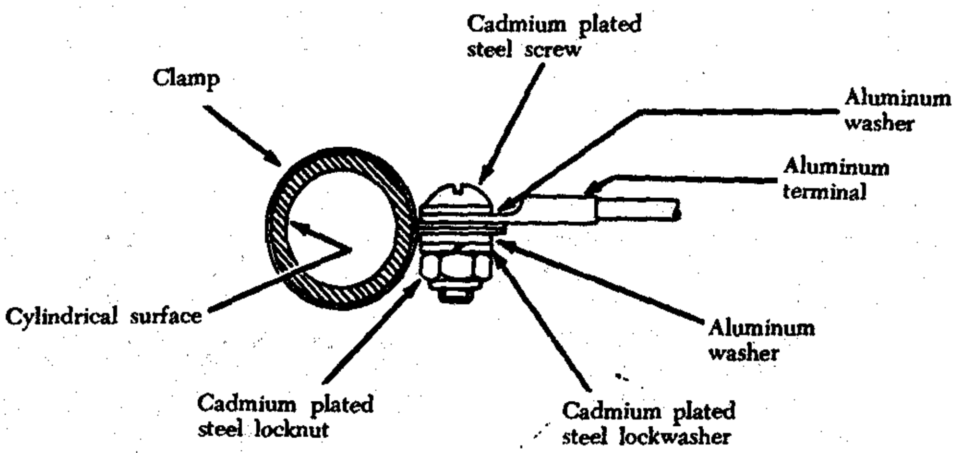
FIGURE 11-37. Connecting terminals to terminal block.



A. Copper jumper connection to tubular structure.



B. Bonding conduit to structure.



C. Aluminum jumper connection to tubular structure.

Figure 11-38. Hardware combinations used in making bonding connections.

(6) Install bonding and grounding connections in protected areas whenever possible.

Bonding jumpers should be kept as short as practicable. The jumper should not interfere with the operation of movable aircraft elements, such as surface controls; normal movement of these elements should not result in damage to the bonding jumper.

Electrolytic action can rapidly corrode a bonding connection if suitable precautions are not observed. Aluminum alloy jumpers are recommended for most cases; however, copper jumpers can be used to bond together parts made of stainless steel, cadimum-plated steel, copper, brass, or bronze. Where contact between dissimilar metals cannot be avoided, the choice of jumper and hardware should be such that corrosion is minimized, and the part most likely to corrode will be the jumper or associated hardware. Figure 11–38 illustrates some proper hardware combinations for making bonding connections. At locations where finishes are removed, a protective finish should be applied to the completed connection to prevent corrosion.

The use of solder to attach bonding jumpers should be avoided. Tubular members should be bonded by means of clamps to which the jumper is attached. The proper choice of clamp material minimizes the probability of corrosion. When bonding jumpers carry a substantial amount of ground return current, the current rating of the jumper should be adequate, and it should be determined that a negligible voltage drop is produced.

Bonding and grounding connections are normally made to flat surfaces by means of through-bolts or screws where there is easy access for installation. Other general types of bolted connections are as follows:

(1) In making a stud connection (figure 11–39), a bolt or screw is locked securely to the structure, thus becoming a stud. Grounding or bonding jumpers can be removed or added to the shank of the stud without removing the stud from the structure.

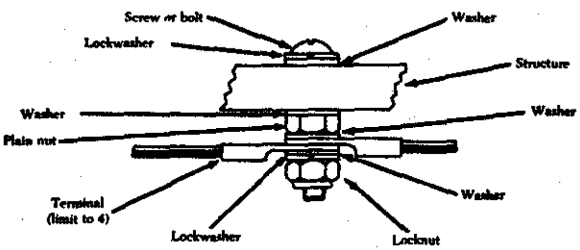


FIGURE 11–39. Stud bonding or grounding to a flat surface.

(2) Nut plates are used where access to the nut for repairs is difficult. Nut plates are riveted or welded to a clean area of the structure (figure 11–40).

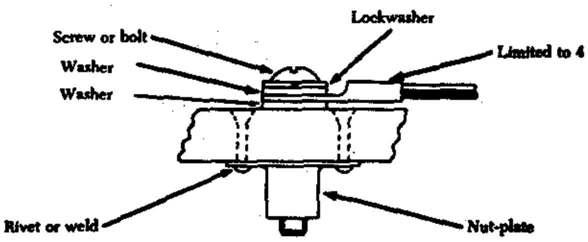


FIGURE 11–40. Nut plate bonding or grounding to a flat surface.

Bonding and grounding connections are also made to a tab riveted to a structure. In such cases it is important to clean the bonding or grounding surface and make the connection as through the connection were being made to the structure. If it is necessary to remove the tab for any reason, the rivets should be replaced with rivets one size larger, and the mating surfaces of the structure and the tab should be clean and free of anodic film.

Bonding or grounding connections can be made to aluminum alloy, magnesium, or corrosion-resistant steel tubular structure as shown in figure 11–41, which shows the arrangement of hardware for bonding with an aluminum jumper. Because of the ease with which aluminum is deformed, it is necessary to distribute the screw and nut pressure by means of plain washers.

Hardware used to make bonding or grounding connections should be selected on the basis of mechanical strength, current to be carried, and ease of installation. If connection is made by aluminum or copper jumpers to the structure of a dissimilar material, a washer of suitable material should be installed between the dissimilar metals so that any corrosion will occur on the washer, which is expendable.

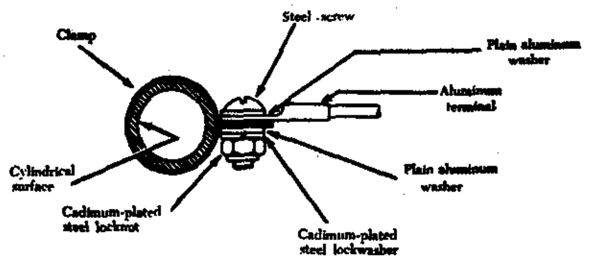


FIGURE 11–37. Bonding or grounding connections to a cylindrical surface.

Hardware material and finish should be selected on the basis of the material of the structure to which attachment is made and on the material of the jumper and terminal specified for the bonding or grounding connection. Either a screw or bolt of the proper size for the specified jumper terminal should be used. When repairing or replacing existing bonding or grounding connections, the same type of hardware used in the original connection should always be used.

Testing Grounds and Bonds

The resistance of all bond and ground connections should be tested after connections are made before re-finishing. The resistance of each connection should normally not exceed 0.003 ohm. Resistance measurements need to be of limited nature only for verification of the existence of a bond, but should not be considered as the sole proof of satisfactory bonding. The length of jumpers, methods, and materials used, and the possibility of loosening the connections in service should also be considered.

CONNECTORS

Connectors (plugs and receptacles) facilitate maintenance when frequent disconnection is required. Since the cable is soldered to the connector inserts, the joints should be individually installed and the cable bundle firmly supported to avoid damage by vibration. Connectors have been particularly vulnerable to corrosion in the past, due to condensation within the shell. Special connectors with waterproof features have been developed which may replace non-waterproof plugs in areas where mositure causes a problem. A connector of the same basic type and design should be used when replacing a connector. Connectors susceptible to corrosion difficulties may be treated with a chemically inert waterproof jelly. When replacing connector assemblies, the socket-type insert should be used on the half which is "live" or "hot" after the connector is disconnected, to prevent unintentional grounding.

Types of Connectors

Connectors are identified by AN numbers and are divided into classes with the manufacturer's variations in each class. The manufacturer's variations are differences in appearance and in the method of meeting a specification. Some commonly used connectors are shown in figure 11–42. There are five basic classes of AN connectors used in most aircraft. Each class of connector has slightly different construction characteristics. Classes A, B, C, and D are made of aluminum, and class K is made of steel.

(1) Class A—Solid, one-piece back shell, general-purpose connector.

(2) Class B—Connector back shell separates into two parts lengthwise. Used primarily where it is important that the soldered connectors be readily accessible. The back shell is held together by a threaded ring or by screws.

(3) Class C—A pressurized connector with inserts that are not removable. Similar to a class A connector in appearance, but the inside sealing arrangement is sometimes different. It is used on walls of bulkheads of pressurized equipment.

(4) Class D—Moisture- and vibration-resistant connector which has a sealing grommet in the back shell. Wires are threaded through tight-fitting holes in the grommet, thus sealing against moisture.

(5) Class K—A fireproof connector used in areas where it is vital that the electric current is not interrupted, even though the connector may be exposed to continuous open flame. Wires are crimped to the pin or socket contacts and the shells are made of steel. This class of connector is normally longer than other classes of connectors.

Connector Identification

Code letters and numbers are marked on the coupling ring or shell to identify a connector. This code (figure 11–43) provides all the information necessary to obtain the correct replacement for a defective or damaged part.

Many special-purpose connectors have been designed for use in aircraft applications. These include subminiature and rectangular shell connectors, and connectors with short body shells or split-shell construction.

FIGURE 11-42. AN connectors.

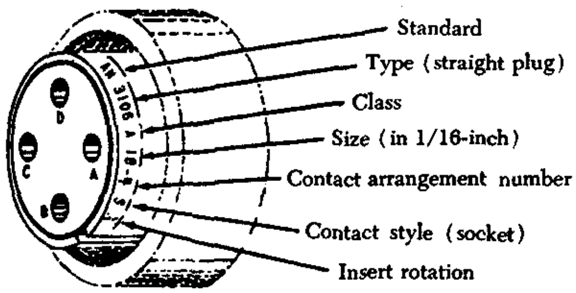


FIGURE 11-43. AN connector marking.

Installation of Connectors

The following procedures outline one recommended method of assembling connectors to receptacles.

(1) Locate the proper position of the plug in relation to the receptable by aligning the key of one part with the groove or keyway of the other part.

(2) Start the plug into the receptacle with a light forward pressure and engage the

threads of the coupling ring and receptacle.

(3) Alternately push in the plug and tighten the coupling ring until the plug is completely seated.

(4) Use connector pliers to tighten coupling rings one sixteenth to one eighth turn beyond fingertight if space around the connector is too small to obtain a good finger grip.

(5) Never use force to mate connectors to receptacles. Do not hammer a plug into its receptacle; and never use a torque wrench or pliers to lock coupling rings.

A connector is generally disassembled from a receptacle in the following manner:

(1) Use connector pliers to loosen coupling rings which are too tight to be loosened by hand.

(2) Alternately pull on the plug body and unscrew the coupling ring until the connector is separated.

(3) Protect disconnected plugs and receptacles with caps or plastic bags to keep debris from entering and causing faults.

(4) Do not use excessive force, and do not pull on attached wires.

CONDUIT

Conduit is used in aircraft installations for the mechanical protection of wires and cables. It is available in metallic and nonmetallic materials in both rigid and flexible form.

When selecting conduit size for a specific cable bundle application, it is common practice to allow for ease in maintenance and possible future circuit expansion by specifying the conduit inner diameter about 25% larger than the maximum diameter of the conductor bundle. The nominal diameter of a rigid metallic conduit is the outside diameter. Therefore, to obtain the inside diameter, subtract twice the tube wall thickness.

From the abrasion standpoint, the conductor is vulnerable at the conduit ends. Suitable fittings are affixed to the conduit ends in such a manner that a smooth surface comes in contact with the conductor within the conduit. When fittings are not used, the conduit end should be flared to prevent wire insulation damage. The conduit is supported by clamps along the conduit run.

Many of the common conduit installation problems can be avoided by proper attention to the following details:

(1) Do not locate conduit where it can be used as a handhold or footstep.

(2) Provide drain holes at the lowest point in a conduit run. Drilling burrs should be carefully removed from the drain holes.

(3) Support the conduit to prevent chafing against the structure and to avoid stressing its end fittings.

Damaged conduit sections should be repaired to prevent damage to the wires or wire bundle. The minimum acceptable tube bend radii for rigid conduit as prescribed by the manufacturer's instructions should be followed carefully. Kinked or wrinkled bends in a rigid conduit are normally not acceptable.

Flexible aluminum conduit is widely available in two types: (1) Bare flexible and (2) rubber-covered conduit. Flexible brass conduit is normally used instead of flexible aluminum conduit, where necessary to minimize radio interference. Flexible conduit may be used where it is impractical to use rigid conduit, such as areas that have motion between conduit ends or where complex bends are necessary. Transparent adhesive tape is recommended when cutting flexible tubing with a hacksaw to minimize fraying of the braid.

ELECTRICAL EQUIPMENT INSTALLATION

This section provides general procedures and safety precautions for installation of commonly used aircraft electrical equipment and components. Electrical load limits, acceptable means of controlling or monitoring electrical loads, and circuit protection devices are subjects with which mechanics must be familiar to properly install and maintain aircraft electrical systems.

Electrical Load Limits

When installing additional electrical equipment that consumes electrical power in an aircraft, the total electrical load must be safely controlled or managed within the rated limits of the affected components of the aircraft's power-supply system.

Before any aircraft electrical load is increased, the associated wires, cables, and circuit protection devices (fuses or circuit breakers) should be checked to determine that the new electrical load (previous maximum load plus added load) does not exceed the rated limits of the existing wires, cables, or protection devices.

The generator or alternator output ratings prescribed by the manufacturer should be compared with the electrical loads which can be imposed on the affected generator or alternator by installed equipment. When the comparison shows that the probable total connected electrical load can exceed the output load limits of the generator(s) or alternator(s), the load should be reduced so that an overload cannot occur. When a storage battery is part of the electrical power system, ensure that the battery is continuously charged in flight, except when short, intermittent loads are connected such as a radio transmitter, a landing-gear motor, or other similar devices which may place short-time demand loads on the battery.

Controlling or Monitoring the Electrical Load

Placards are recommended to inform crewmembers of an aircraft about the combination of electrical loads that can safely be connected to the power source.

In installations where the ammeter is in the battery lead, and the regulator system limits the maximum current that the generator or alternator can deliver, a voltmeter can be installed on the system bus. As long as the ammeter does not read "discharge" (except for short, intermittent loads such as operating the gear and flaps) and the voltmeter remains at "system voltage," the generator or alternator will not be overloaded.

In installations where the ammeter is in the generator or alternator lead, and the regulator system does not limit the maximum current that the generator or alternator can deliver, the ammeter can be redlined at 100% of the generator or alternator rating. If the ammeter reading is never allowed to exceed the red line, except for short, inermittent loads, the generator or alternator will not be overloaded.

Where the use of placards or monitoring devices is not practicable or desired, and where assurance is needed that the battery in a typical small aircraft generator/battery power source will be charged in flight, the total continuous connected electrical load may be held to approximately 80% of the total rated generator output capacity. (When more than one generator is used in parallel, the total rated output is the combined output of the installed generators.)

When two or more generators are operated in parallel and the total connected system load can exceed the rated output of one generator, means must be provided for quickly coping with the sudden overloads which can be caused by generator or engine failure. A quick load reduction system, or a specified procedure whereby the total load can be reduced to a quantity which is within the rated capacity of the remaining operable generator(s), can be employed.

Electrical loads should be connected to inverters, alternators, or similar aircraft electrical power sources in such a manner that the rated limits of the power source are not exceeded, unless some type of effective monitoring means is provided to keep the load within prescribed limits.

Circuit Protection Devices

Conductors should be protected with circuit breakers or fuses located as close as possible to the electrical power source bus. Normally, the manufacturer of the electrical equipment specifies the fuse or circuit breaker to be used when installing equipment.

The circuit breaker or fuse should open the circuit before the conductor emits smoke. To accomplish this, the time current characteristic of the protection device must fall below that of the associated conductor. Circuit protector characteristics should be matched to obtain the maximum utilization of the connected equipment.

Figure 11–44 shows an example of the chart used in selecting the circuit breaker and fuse protection for copper conductors. This limited chart is applicable to a specific set of ambient temperatures and wire bundle sizes, and is presented as a typical example only. It is important to consult such guides before selecting a conductor for a specific purpose. For example, a wire run individually in the open air may be protected by the circuit breaker of the next higher rating to that shown on the chart.

Wire AN gage copper	Circuit breaker amperage	Fuse amp.
22	5	5
20	7.5	5
18	10	10
16	15	10
14	20	15
12	30	20
10	40	30
8	50	50
6	80	70
4	100	70
2	125	100
1		150
0		150

FIGURE 11–44. Wire and circuit protector chart.

All re-settable circuit breakers should open the circuit in which they are installed regardless of the position of the operating control when an overload or circuit fault exists. Such circuit breakers are referred to as "trip-free." Automatic re-set circuit breakers automatically re-set themselves. They should not be used as circuit protection devices in aircraft.

Switches

A specifically designed switch should be used in all circuits where a switch malfunction would be hazardous. Such switches are of rugged construction and have sufficient contact capacity to break, make, and carry continuously the connected load current. Snap-action design is generally preferred to obtain rapid opening and closing of contacts regardless of the speed of the operating toggle or plunger, thereby minimizing contact arcing.

The nominal current rating of the conventional aircraft switch is usually stamped on the switch housing. This rating represents the continuous current rating with the contacts closed. Switches should be derated from their nominal current rating for the following types of circuits:

(1) High rush-in circuits—Circuits containing incandescent lamps can draw an initial current which is 15 times greater than the continuous current. Contact burning or welding may occur when the switch is closed.

(2) Inductive circuits—Magnetic energy stored in solenoid coils or relays is released and appears as an arc when the control switch is opened.

(3) Motors—Direct-current motors will draw several times their rated current during starting, and magnetic energy stored in their armature and field coils is released when the control switch is opened.

The chart in figure 11–45 is typical of those available for selecting the proper nominal switch rating when the continuous load current is known. This selection is essentially a derating to obtain reasonable switch efficiency and service life.

Hazardous errors in switch operation can be avoided by logical and consistent installation. Two-position "on-off" switches should be mounted so that the "on" position is reached by an upward or forward movement of the toggle. When the switch controls movable aircraft elements, such as landing gear or flaps, the toggle should move in the same direction as the desired motion. Inadvertent operation of a switch can be prevented by mounting a suitable guard over the switch.

Nominal system voltage	Type of load	Derating factor
24 v. d.c.	Lamp	8
24 v. d.c.	Inductive (Relay-Solenoid)	4
24 v. d.c.	Resistive (Heater)	2
24 v. d.c.	Motor	3
12 v. d.c.	Lamp	5
12 v. d.c.	Inductive (Relay-Solenoid)	2
12 v. d.c.	Resistive (Heater)	1
12 v. d.c.	Motor	2

FIGURE 11–45. Switch derating factors.

Relays

Relays are used as switching devices where a weight reduction can be achieved or electrical controls can be simplified. A relay is an electrically operated switch and is therefore subject to dropout under low system voltage conditions. The foregoing discussion of switch ratings is generally applicable to relay contact ratings.

AIRCRAFT LIGHTING SYSTEMS

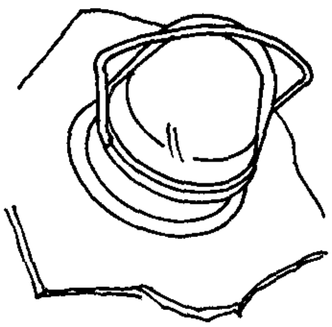
Aircraft lighting systems provide illumination for both exterior and interior use. Lights on the exterior provide illumination for such operations as landing at night, inspection of icing conditions, and safety from midair collision. Interior lighting provides illumination for instruments, cockpits, cabins, and other sections occupied by crewmembers and passengers. Certain special ights, such as indicator and warning lights, indicate the operational status of equipment.

Exterior Lights

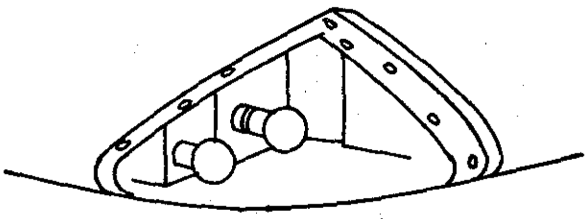
Position, anti-collision, landing, and taxi lights are common examples of aircraft exterior lights. Some lights, such as position lights and anti-collision lights, are required for night operations. Other types of exterior lights, such as wing inspection lights, are of great benefit for specialized flying operations.

Position Lights

Aircraft operating at night must be equipped with position lights that meet the minimum requirements specified by the Federal Aviation Regulations. A set of position lights consist of one red, one



A. Tail position light unit.



B. Wingtip position light unit.

FIGURE 11–46. Position lights.

green, and one white light. Position lights are sometimes referred to as "navigation" lights. On many aircraft each light unit contains a single lamp mounted on the surface of the aircraft (A of figure 11–46). Other types of position light units contain two lamps (B of figure 11–46), and are often streamlined into the surface of the aircraft structure

The green light unit is always mounted at the extreme tip of the right wing The red unit is mounted in a similar position on the left wing The white unit is usually located on the vertical stabilizer in a position where it is clearly visible through a wide angle from the rear of the aircraft

The wingtip lamps and the tail lamps are controlled by a double-pole, single-throw switch in the pilot's compartment. On "dim", the switch connects a resistor in series with the lamps Since the resistor decreases current flow, the light intensity is reduced. On "bright", the resistor is shorted out of the circuit, and the lamps glow at full brilliance

On some types of installations a switch in the pilot's compartment provides for steady or flashing operation of the position lights. For flashing operation, a flasher mechanism is usually installed in the position light circuit. It consists essentially of a motor-driven camshaft on which two cams are mounted and a switching mechanism made up of two breaker arms and two contact screws. One breaker arm supplies d.c. current to the wingtip light circuit through one contact screw, and the other breaker arm supplies the tail light circuit through the other contact screw. When the motor rotates, it turns the camshaft through a set of reduction gears and causes the cams to operate the

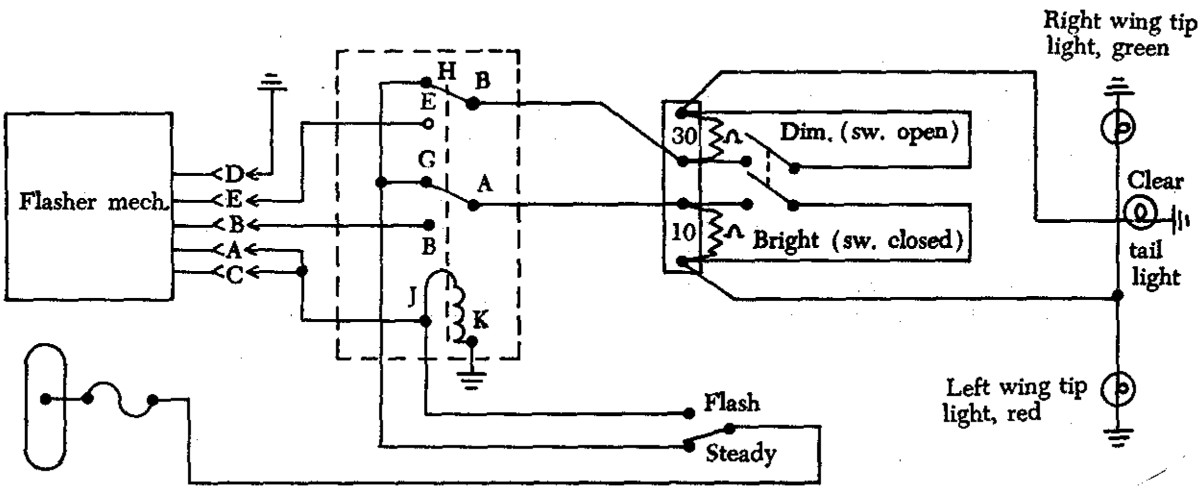


FIGURE 11–47. Position light circuitry.

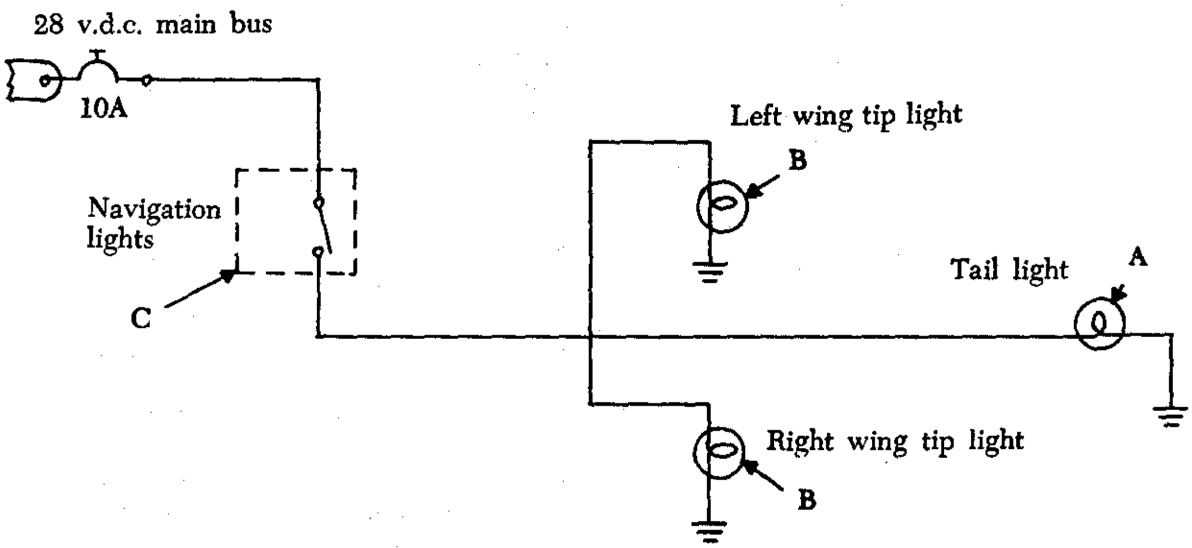


FIGURE 11–48. Single-circuit position light circuitry without flasher.

breaker which opens and closes the wing and tail light circuits alternately. Figure 11–47 is a simplified schematic diagram of a navigation light circuit which illustrates one type of position light circuitry.

The schematic diagram of another type of position light circuitry is shown in figure 11–48. Control of the position lights by a single on-off toggle switch provides only a steady illumination. There is no flasher and no dimming rheostat.

There are, of course, many variations in the position light circuits used on different aircraft. All circuits are protected by fuses or circuit breakers, and many circuits include flashing and dimming equipment. Still others are wired to energize a special warning light dimming relay, which causes all the cockpit warning lights to dim perceptibly when the position lights are illuminated.

Small aircraft are usually equipped with a simplified control switch and circuitry. In some cases, one control knob or switch is used to turn on several sets of lights; for example, one type utilizes a control knob, the first movement of which turns on the position lights and the instrument panel lights. Further rotation of the control knob increases the intensity of only the panel lights. A flasher unit is seldom included in the position light circuitry of very light aircraft, but is used in small twin-engine aircraft.

Anti-collision Lights

An anti-collision light system may consist of one or more lights. They are rotating beam lights which are usually installed on top of the fuselage or tail in such a location that the light will not affect the vision of the crewmember or detract from the conspicuousness of the position lights. In some cases one of the lights is mounted on the underside of the fuselage.

The simplest means of installing an anti-collision light is to secure it to a reinforced fuselage skin panel, as shown in figure 11–49.

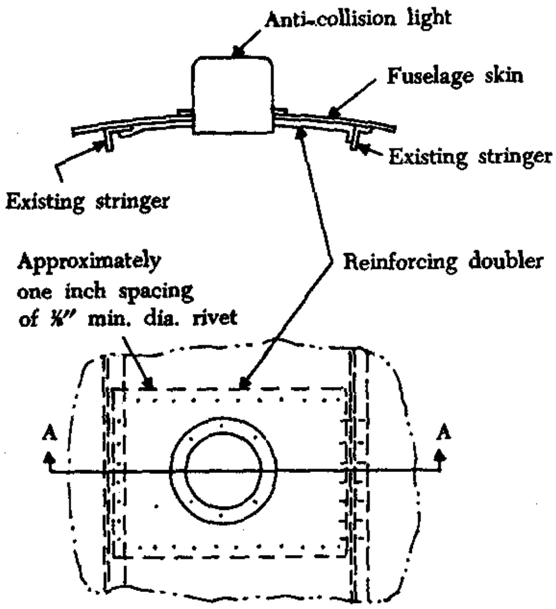


FIGURE 11–49. Typical anti-collision light installation in an unpressurized skin panel.

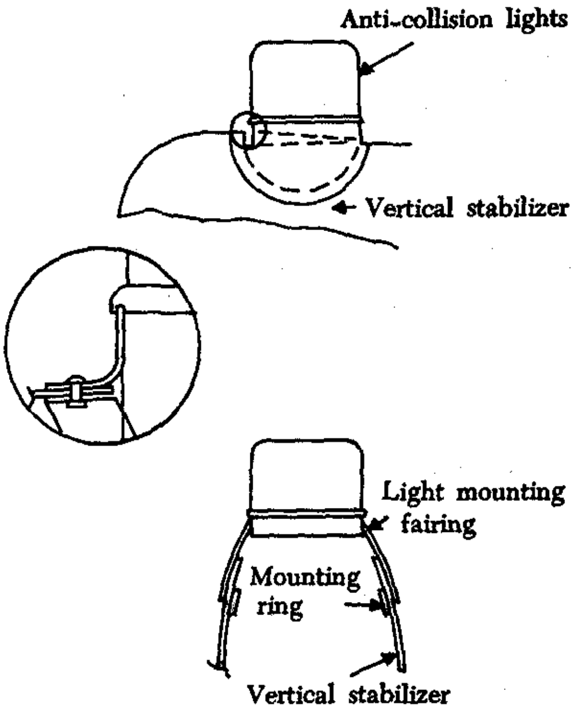


FIGURE 11-50. Typical anti-collision light installation in a vertical stabilizer.

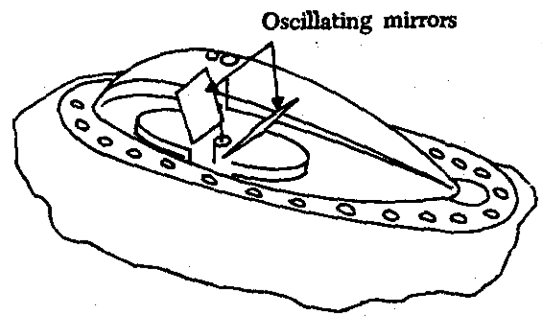


FIGURE 11-51. Anti-collision light.

An anti-collision light is often installed on top of the vertical stabilizer if the cross section of the stabilizer is large enough to accommodate the installation, and if aircraft flutter and vibration characteristics are not adversely affected. Such installations should be located near a spar, and formers should be added as required to stiffen the structure near the light. Figure 11-50 shows a typical anti-collision light installation in a vertical stabilizer.

An anti-collision light unit usually consists of one or two rotating lights operated by an electric motor. The light may be fixed, but mounted under rotating mirrors inside a protruding red glass housing. The mirrors rotate in an arc, and the resulting flash rate is between 40 and 100 cycles per minute. (See figure 11-51.) The anti-collision light is a safety light to warn other aircraft, especially in congested areas.

Landing Lights

Landing lights are installed in aircraft to illuminate runways during night landings. These lights are very powerful and are directed by a parabolic reflector at an angle providing a maximum range of illumination. Landing lights are usually located midway in the leading edge of each wing or streamlined into the aircraft surface. Each light may be controlled by a relay, or it may be connected directly into the electric circuit.

Since icing of the lamp lenses reduces the illumination quality of a lamp, some installations use retractable landing lamps (figure 11-52). When the lamps are not in use, a motor retracts them into receptacles in the wing where the lenses are not exposed to the weather.

As shown in figure 11-53, one type of retractable landing light motor has a split-field winding. Two of the field winding terminals connect to the two outer terminals of the motor control switch through the points of contacts C and D, while the center terminal connects to one of two motor brushes. The brushes connect the motor and magnetic brake sole-

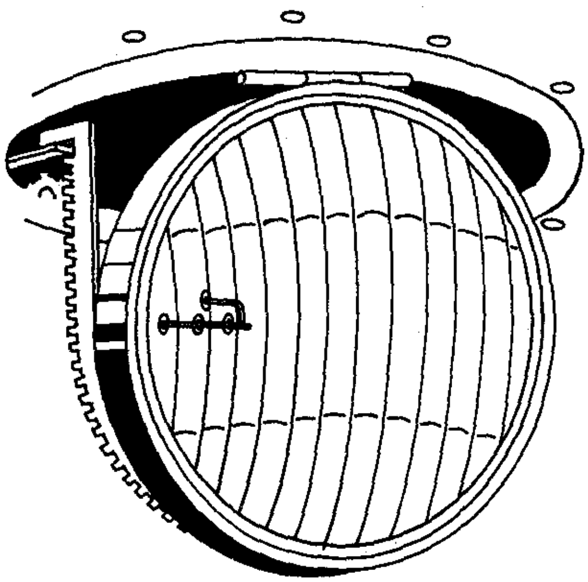


FIGURE 11-52. Retractable landing light.

noid into the electric circuit. The points of contact C are held open by the geared quadrant of the landing lamp mechanism. The points of contact D are held closed by the tension of the spring to the right of the contacts. This is a typical arrangement of a landing lamp circuit when the landing lamp is retracted and the control switch is in the "off" position. No current flows in the circuit, and neither the motor nor the lamp can be energized.

When the control switch is placed in the upper, or "extend," position (figure 11–53), current from the battery flows through the closed contacts of the switch, the closed contacts of contact D, the center terminal of the field winding, and the motor itself. Current through the motor circuit energizes the brake solenoid, which withdraws the brake shoe from against the motor shaft, allowing the motor to turn and lower the lamp mechanism. After the lamp mechanism moves about 10°, contact A touches and rides along the copper bar B. In the meantime, relay F is energized, and its contacts close. This permits current to flow through the copper bar B, contact A, and the lamp. When the lamp mechanism is completely lowered, the projection at the top of the gear quadrant pushes the D contacts apart, opens the circuit to the motor, and causes the de-energized brake solenoid to release the brake. The brake is pushed against the motor shaft by the spring, stopping the motor and completing the lowering operation.

To retract the landing lamp, the control switch is placed in the "retract" position (figure 11–53). The motor and brake circuits are completed through the points of contact C, since these contacts are closed when the gear quadrant is lowered. This action completes the circuit, the brake releases, the motor turns (this time in the opposite direction) and the landing light mechanism is retracted. Since switching to "retract" breaks the circuit to relay F, the relay contacts open, disconnecting the copper bar and causing the landing lamp to go out. When the mechanism is completely retracted, contact points C open, and the circuit to the motor is again broken, the brake applied, and the motor stopped.

Retractable landing lights that can be extended to any position of their extension are employed on some aircraft. Landing lights used on high-speed aircraft are usually equipped with an airspeed pressure switch which prevents extension of landing lights at excessive airspeeds. Such switches also cause retraction of landing lights if the aircraft exceeds a predetermined speed.

Many large aircraft are equipped with four landing lights, two of which are fixed and two retractable. Fixed lights are usually located in either the wing root areas or just outboard of the fuselage in the leading edge of each wing. The two retractable lights are usually located in the lower outboard surface of each wing, and are normally controlled by separate switches. On some aircraft, the fixed

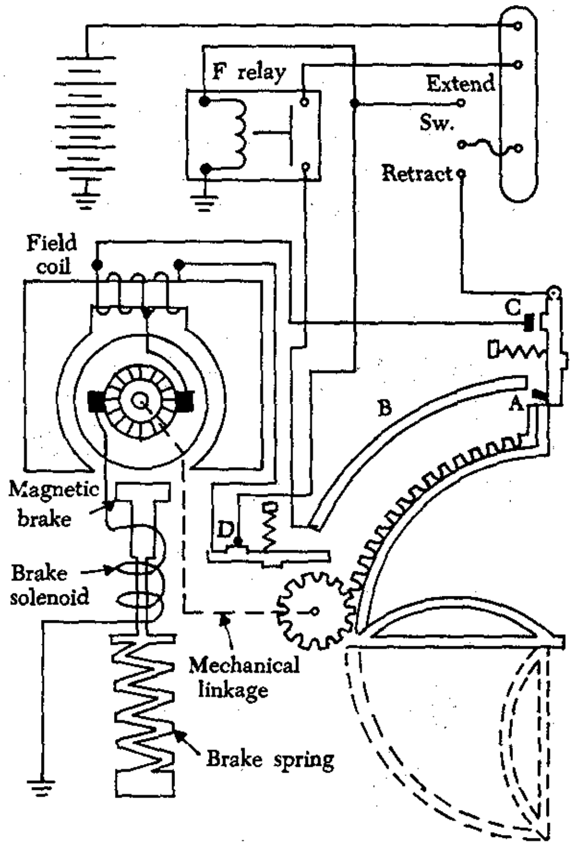


FIGURE 11–53. Landing light mechanism and circuit.

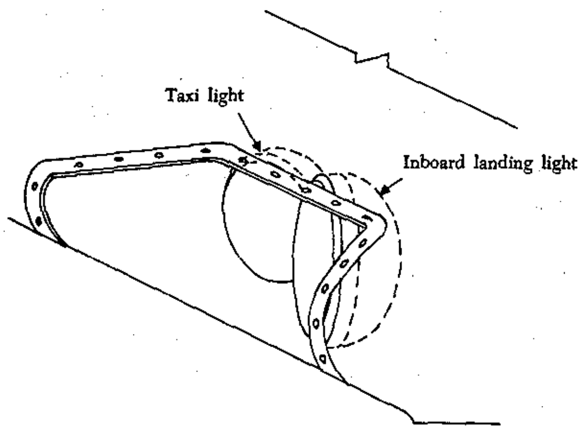


FIGURE 11–54. Fixed landing light and taxi light.

landing light is mounted in an area with a taxi light, as shown in figure 11–54.

Taxi Lights

Taxi lights are designed to provide illumination on the ground while taxiing or towing the aircraft to or from a runway, taxi strip, or in the hangar area.

Taxi lights are not designed to provide the degree of illumination necessary for landing lights; 150- to 250-watt taxi lights are typical on many medium and heavy aircraft.

On aircraft with tricycle landing gear, either single or dual taxi lights are often mounted on the non-steerable part of the nose landing gear. As illustrated in figure 11–55, they are positioned at an oblique angle to the center line of the aircraft to provide illumination directly in front of the aircraft and also some illumination to the right and left of the aircraft's path. On some aircraft the dual taxi lights are supplemented by wingtip clearance lights controlled by the same circuitry.

Taxi lights are also mounted in the recessed areas of the wing leading edge, often in the same area with a fixed landing light.

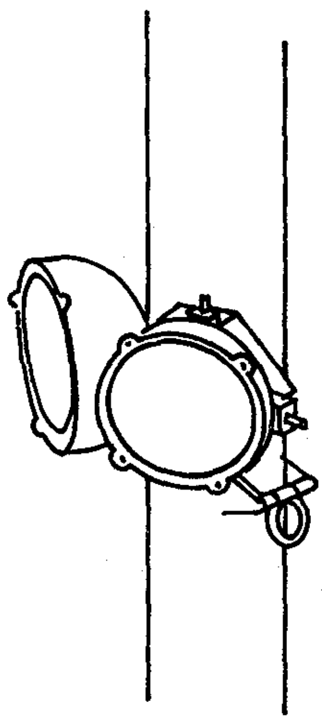


FIGURE 11–55. Taxi lights mounted on non-steerable portion of nose landing gear.

Many small aircraft are not equipped with any type of taxi light, but rely on the intermittent use of a landing light to illuminate taxiing operations. Still other aircraft utilize a dimming resistor in the landing light circuit to provide reduced illumination for taxing. A typical circuit for dual taxi lights is shown in figure 11–56.

Some large aircraft are equipped with alternate taxi lights located on the lower surface of the aircraft, aft of the nose radome. These lights, operated by a separate switch from the main taxi lights, illuminate the area immediately in front of and below the aircraft nose.

Wing Inspection Lights

Some aircraft are equipped with wing inspection lights to illuminate the leading edge of the wings to permit observation of icing and general condition of these areas in flight. On some aircraft, the wing inspection light system (also called wing ice lights) consists of a 100-watt light mounted flush on the outboard side of each nacelle forward of the wing. These lights permit visual detection of ice formation on wing leading edges while flying at night. They are also often used as floodlights during ground servicing. They are usually controlled through a relay by an "on-off" toggle switch in the cockpit.

Some wing inspection light systems may include or be supplemented by additional lights, sometimes called nacelle lights, that illuminate adjacent areas such as cowl flaps or the landing gear. These are normally the same type of lights and can be controlled by the same circuits.

MAINTENANCE AND INSPECTION OF LIGHTING SYSTEMS

Inspection of an aircraft's lighting systems normally includes checking the condition and security of all visible wiring, connections, terminals, fuses, and switches. A continuity light or meter can be used in making these checks, since the cause of many troubles can often be located by systematically testing each circuit for continuity.

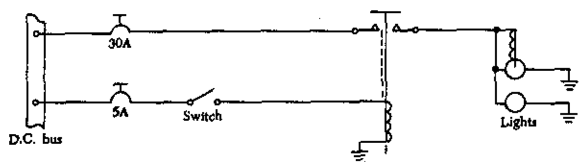


FIGURE 11–56. Typical taxi light circuit.

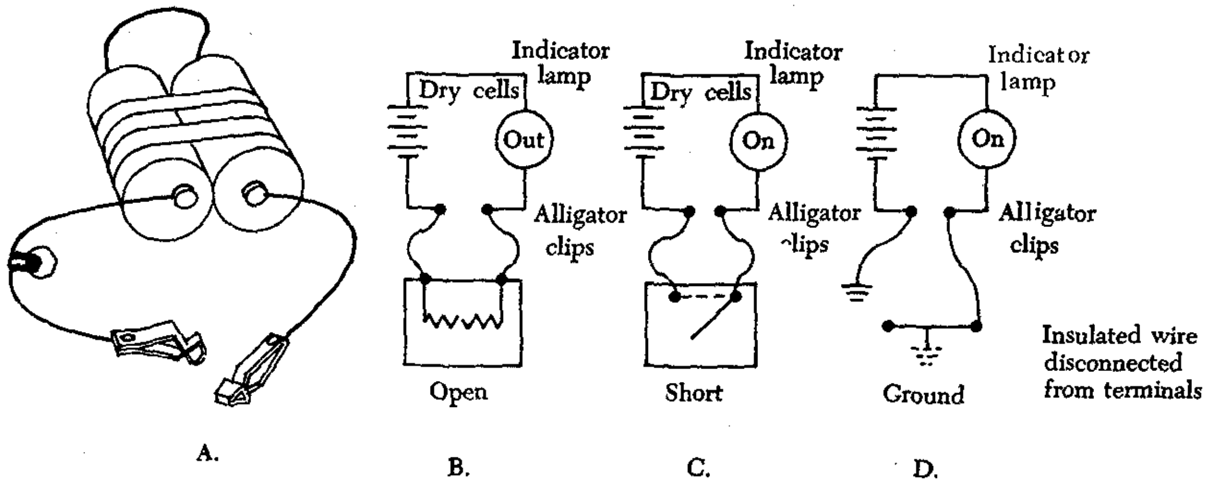


FIGURE 11-57. Continuity testing with a continuity tester.

All light covers and reflectors should be kept clean and polished. Cloudy reflectors are often caused by an air leak around the lens.

The condition of the sealing compound around position light frames should be inspected regularly. Leaks or cracks should be filled with an approved sealing compound.

Care should be exercised in installing a new bulb in a light assembly, since many bulbs fit into a socket in only one position and excessive force can cause an incomplete or open circuit in the socket area.

Circuit testing, commonly known as troubleshooting is a means of systematically locating faults in an electrical system. These faults are usually of three kinds:

(1) Open circuits in which leads or wires are broken.

(2) Shorted circuits in which grounded leads cause current to be returned by shortcuts to the source of power.

(3) Low power in circuits causing lights to burn dimly and relays to chatter. Electrical troubles may develop in the unit or in the wiring. If troubles such as these are carefully analyzed and systematic steps are taken to locate them, much time and energy not only can be saved, but damage to expensive testing equipment often can be avoided. (For a more extensive treatment of circuit testing than the summary provided here, refer to Chapter 8, Airframe and Powerplant Mechanics General Handbook, AC 65-9A.)

The equipment generally used in testing lighting circuits in an aircraft consists of a voltmeter, test light, continuity meter, and ohmmeter.

Although any standard d.c. voltmeter with flexible leads and test prods is satisfactory for testing circuits, portable voltmeters especially designed for test purposes are usually used.

The test lamp consists of a low wattage aircraft light. Two leads are used with this light.

Continuity testers vary somewhat. One type consists of a small lamp connected in series with two small batteries (flashlight batteries are very suitable) and two leads. (See A of figure 11-57.) Another type of continuity tester contains two batteries connected in series with a d.c. voltmeter and two test leads. A completed circuit will be registered by the voltmeter.

Whenever generator or battery voltage is available, the voltmeter and the test light can be used in circuit testing, since these sources of power will activate the test light and the voltmeter.

If no electrical power is available (the circuit is dead), then the continuity tester is used. The self-contained batteries of the continuity tester force current through the circuit, causing the continuity meter to indicate when the circuit being tested is completed. When using the continuity meter, the circuit being tested should always be isolated from all other circuits by removing the fuse, by opening the switch, or by disconnecting the wires.

Figure 11-57 illustrates techniques which may be used in checking circuits. The continuity tester contains a light to serve as an indicator. When the test leads are touched together, a complete circuit is established and the indicator light illuminates. When the leads are brought into contact with a resistor or other circuit element, as shown in B of figure 11–57, and the light does not illuminate, then the circuit being tested is open.

For the open test to be conclusive, be sure the resistance of the unit tested is low enough to permit the lamp to light. In a test in which the resistance is too high, usually more than 10 ohms, connect a voltmeter in the circuit in place of the lamp. If the voltmeter pointer fails to deflect, an open circuit is indicated.

The test for shorts (C of figure 11–57) shows the continuity tester connected across the terminals of a switch in the "open" position. If the tester lamp lights, there is a short circuit in the switch.

To determine whether a length of wire is grounded at some point between its terminals, disconnect the wire at each end and hook one test clip to the wire at one end and ground the other test clip (D of figure 11–57). If the wire is grounded, the lamp will light. To locate the ground, check back at intervals toward the other end. The lighting of the lamp will indicate the section of the wire that is grounded.

The ohmmeter, although primarily designed to measure resistance, is useful for checking continuity. With an ohmmeter, the resistance of a lighting circuit can be determined directly by scale. Since an open circuit has infinite resistance, a zero reading on the ohmmeter indicates circuit continuity.

As illustrated in figure 11–58, the ohmmeter uses a battery as the source of voltage. There are fixed resistors, which are of such value that when the test prods are shorted together, the meter will read full scale. The variable resistor, in parallel with the meter, and the fixed resistors compensate for changes in voltage of the battery. The variable resistor provides for zero adjustment on the meter control panel.

On the meter there may be several scales, which are made possible by various values of resistance and battery voltage. The desired scale is selected by a selector switch on the face of the ohmmeter. Each scale reads low resistances at the upper end. Greater resistance in a circuit is indicated by less deflection of the indicator on the scale.

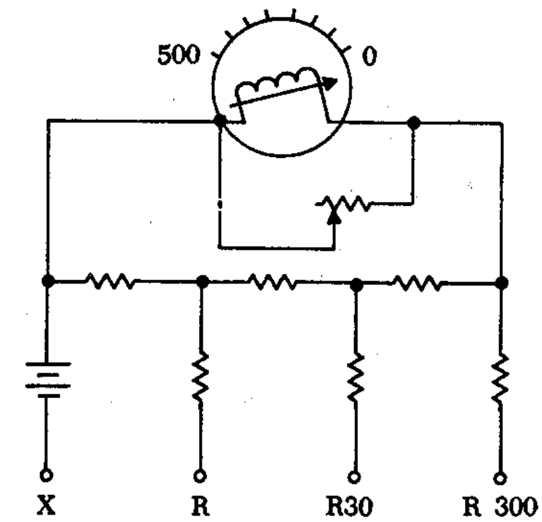


FIGURE 11–58. Typical ohmmeter internal circuitry.

When using an ohmmeter to check continuity, connect the leads across the circuit. A zero ohm reading indicates circuit continuity. For checking resistance, a scale should be chosen which will contain the resistance of the element being measured. In general, a scale should be selected on which the reading will fall in the upper half of the scale. Short the leads together and set the meter to read zero ohm by the zero adjustment. If a change in scales is made anytime, remember to re-adjust the meter to zero ohm.

When making circuit tests with the ohmmeter, never attempt to check continuity or measure the resistance in a circuit while it is connected to a source of voltage. Disconnect one end of an element when checking resistance, so that the ohmmeter will not read the resistance of parallel paths.

The following summary of continuity testing of lighting circuits is recommended, using either an ohmmeter or any other type of continuity tester.

(1) Check the fuse or circuit breaker. Be sure it is the correct one for the circuit being tested.

(2) Check the electrical unit (light).

(3) If fuse or circuit breaker and light are in good condition, check at the most accessible point for an open or short in the circuit.

(4) Never guess. Always locate the trouble in the positive lead of a circuit, the operating

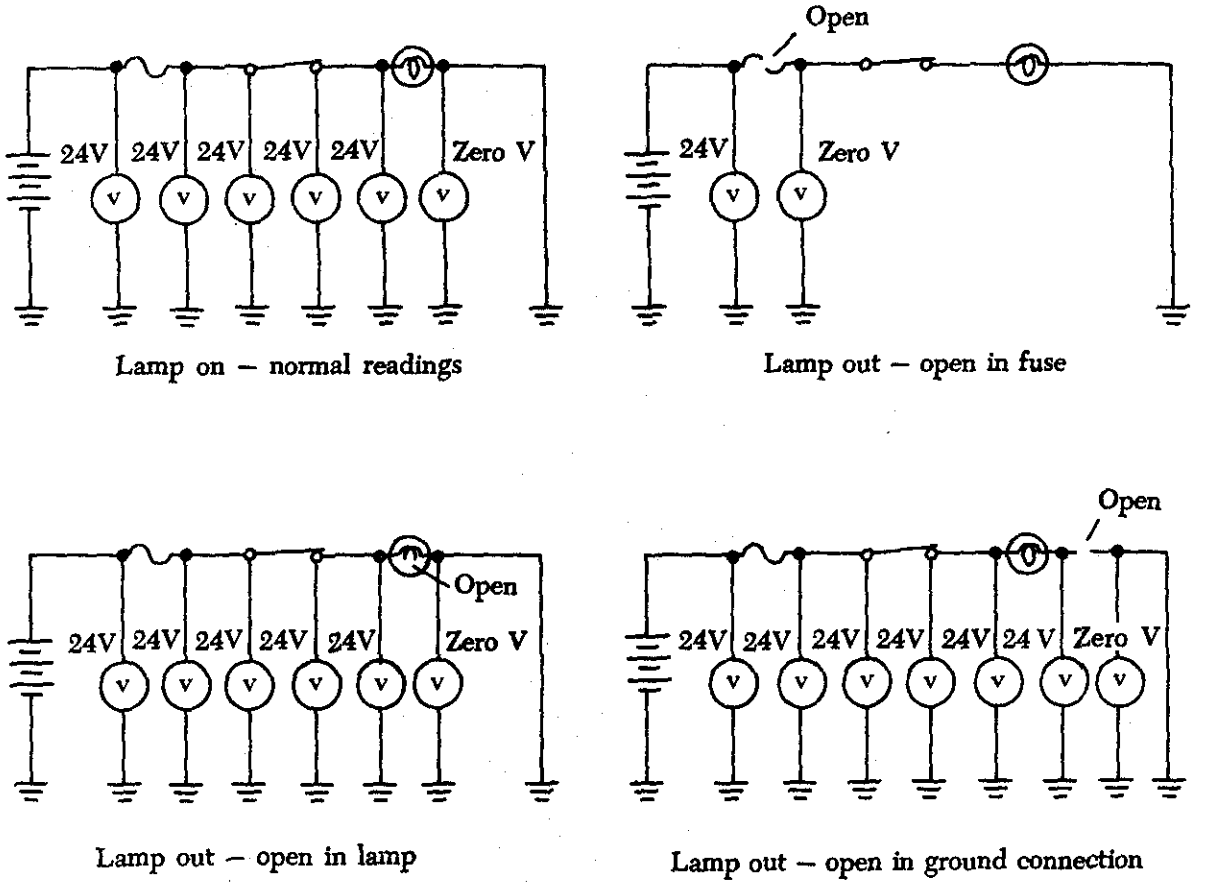


FIGURE 11–59. Continuity testing with a voltmeter.

unit, or the negative lead before removing any equipment or wires.

A voltmeter with long flexible leads provides a satisfactory, though different, method of checking the continuity of lighting system wiring in an aircraft. The voltage to be checked by the voltmeter is furnished by the storage battery in the aircraft.

The following procedure indicates the steps for continuity checking by a voltmeter in a circuit which consists of a 24-volt battery, a fuse, a switch, and a landing lamp.

(1) Draw a simple wiring diagram of the circuitry to be tested, as shown in figure 11–59.

(2) Check the fuse by touching the positive voltmeter lead to the load end of the fuse and the negative lead to ground. If the fuse is good, there will be an indication on the voltmeter. If it is burned out, it must be replaced. If it burns out again, the circuit is grounded. Check for the ground at the lamp by removing the connector and replacing the fuse; if it burns out, the short is in the line. However, if the fuse does not burn out this time, the short is within the lamp.

(3) If the fuse tests good, the circuit has an open. Then with the negative clip of the voltmeter connected to ground, move the positive clip from point to point along the circuit, following the diagram as a guide. Test each unit and length of wire. The first zero reading on the voltmeter indicates that there is an open circuit between the last point at which the voltage was normal and the point of the first zero reading. In the illustration of figure 11–59, open circuits are caused by an open fuse, an open lamp filament, and an open lamp-to-ground connection.